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The Biologic and Economic Assessment of the Field Crop Usage of Chlorpyrifos

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Contents

Executive Summary

NAPIAP initiated the chlorpyrifos assessment because of reregistration concerns expressed to USDA by the Environmental Protection Agency in the spring of 1990. Chlorpyrifos (brand name Lorsban) is used to control a variety of leaf-feeding insects, spider mites, and soil insects, as well as some diseases on field, fruit, nut, vegetable, and selected terrestrial non-food crops. This assessment addresses the uses of chlorpyrifos and examines the impacts if granular and sprayable formulations of chlorpyrifos were unavailable in U.S. agriculture.

Use of Chlorpyrifos

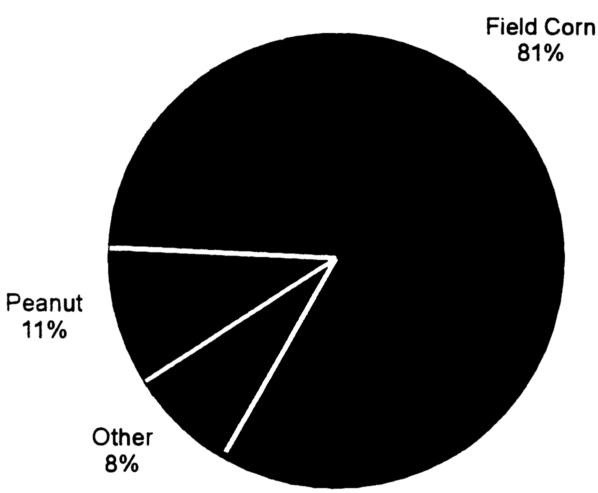
Chlorpyrifos that is used in agriculture is formulated as a 15 percent granular (15G), 4 pound per gallon emulsifiable concentrate (4E), and 50 percent wettable powder (50WP). Chlorpyrifos 15G is registered on 8 field crops, 13 vegetable crops, and citrus. The sprayable formulations (4E and 50WP) are registered on 15 field crops, 11 fruit crops, 4 nut crops, and more than 25 vegetable crops. Chlorpyrifos can also be used as a seed treatment. Section 18 and 24C supplemental labels are operative on 22 crops in 24 States. Some growers perceive chlorpyrifos, which is a "General Use" pesticide, to be safer than alternative insecticides, which are "Restricted Use" pesticides (RUP). This is because applicators of Restricted Use pesticides must be certified and licensed to apply RUP's.

An estimated average of 20 million acres of U.S. crops was treated with 21 million lb active ingredient (a.i.) of chlorpyrifos annually from 1987 through 1989. This estimate excludes chlorpyrifos uses for greenhouse, nursery, and sod production as well as the uses of chlorpyrifos products under the Dursban label. Slightly more than 10 million lb a.i. of chlorpyrifos 15G were used annually, of which 81 percent was used on corn, 11 percent on peanut, and the remaining 8 percent on other registered commodities (Figure 1). Approximately 11 million lb a.i. of sprayable formulations were used annually, with 16 percent used on alfalfa, 14 percent on corn, 13 percent on cotton, 10 percent on soybean, 9 percent each on wheat and citrus, and the remaining 29 percent on other labeled fruit, nut, and vegetable crops (Figure 1).

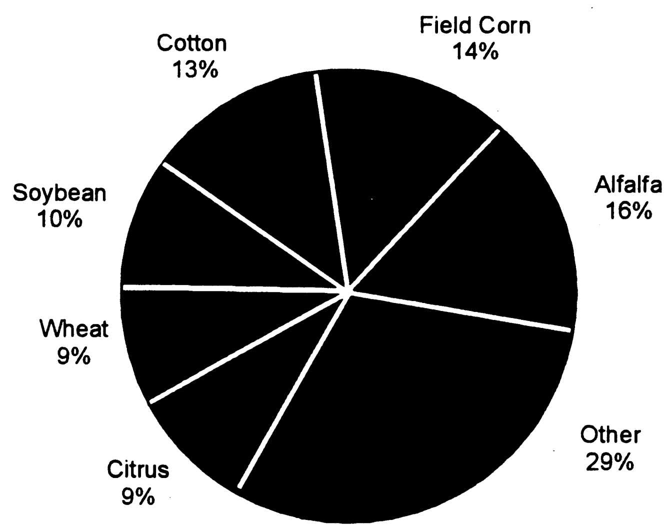
Chlorpyrifos is a critical pest management tool for a number of insects on U.S. agricultural crops. The loss of chlorpyrifos would have significant economic impacts on the following pest/crop combinations: Russian wheat aphid on wheat; redbacked cutworm in alfalfa; cutworms in grass seed production; wireworm in tobacco; spider mites in soybean; grape root borer on grape; *sparganothis* fruitworm, cranberry weevil, blackheaded fireworm, and cranberry fruitworm on cranberry; cabbage root maggot on rutabaga; the insect complex on asparagus; root maggots in onion; fire ant in pecan orchards; ant control in citrus (fire ant, red harvester ant, Argentine ant, and southern fire ant); and an insect complex on sweetpotato in the Southeastern United States.

Chlorpyrifos is a key alternative in insecticide resistance management programs on several commodities, especially in pest management programs for early season cutworms on cot-

Figure 1. Chlorpyrifos Crop Usage by Formulations
[Average granular use = 10,036,000 lb a.i.; average sprayable use = 11,169,000 lb a.i.]



Chlorpyrifos 15G



Chlorpyrifos 4E and 50WP

ton. Reducing the number of alternatives for resistance management programs accelerates resistance development in target pests.

Economic Impact of Cancellation

The net short-run economic loss to the U.S. economy if the insecticide chlorpyrifos were unavailable would be approximately $150 million annually. Fruits, nuts, and vegetables would account for 55 percent of the total dollar impact, although these usages account for only 14 percent of the total chlorpyrifos usage. Few cost-effective alternatives are available for most fruits, nuts, and vegetables. The loss would be $37 million if 15G were lost and $86 million if the sprayable formulations were unavailable.

Because the two formulations of chlorpyrifos can be used as alternatives for each other to manage certain insects on vegetable crops, banning all formulations would add $28 million to the impacts. The loss of both formulations of chlorpyrifos would increase the impacts on cauliflower to $11 million, onions to $10 million, radishes to $3 million, rutabagas to $3 million, and turnips to $1 million. These estimates are based on the current use of chlorpyrifos, the alternative insecticides and pest management practices that would be used if the registration of chlorpyrifos were withdrawn, and the changes in yield and control costs that would result from the use of these alternatives. Figure 2 illustrates the economic impact of chlorpyrifos cancellation.

Of the $37-million loss to U.S. agriculture without chlorpyrifos 15G, approximately $30 million would be attributed to field crops, including peanut, sugarbeet, and soybean, and $7 million to a variety of vegetable crops (Table 1). The impact on field corn, which accounts for 80 percent of 15G use, and on popcorn would be insignificant because cost-effective alternatives are available. The benefits of chlorpyrifos would be higher if one or more of the alternative corn rootworm insecticides were absent from the market. The reasons for the broad usage of chlorpyrifos by U.S. corn growers are that it is an effective, comparatively priced, moderately toxic, broad-spectrum insecticide that has good compatibility with sulfonyl urea herbicides.

Of the $86-million loss if chlorpyrifos sprayable formulations were unavailable, $37 million would be attributed to field crops (including $29 million to alfalfa and $5 million to cotton), $34 million to fruit crops (including $10 million to cranberry, $9 million to apple, $7 million to strawberry, and $6 million to citrus), $4 million to nut crops (of which 90 percent occurs on walnut), and $11 million to vegetables (including $6 million to mint, $2 million to head cabbage and to sweetpotato, and $1 million to brussels sprout) (Table 2). Without chlorpyrifos, many growers of these crops would be forced to grow alternative crops or go out of business.

Figure 2. Economic Losses of Cancelling Chlorpyifos, by Commodity Type
[Net economic loss for granular = $36,862,000; for emulsifiable = $85,967,000]

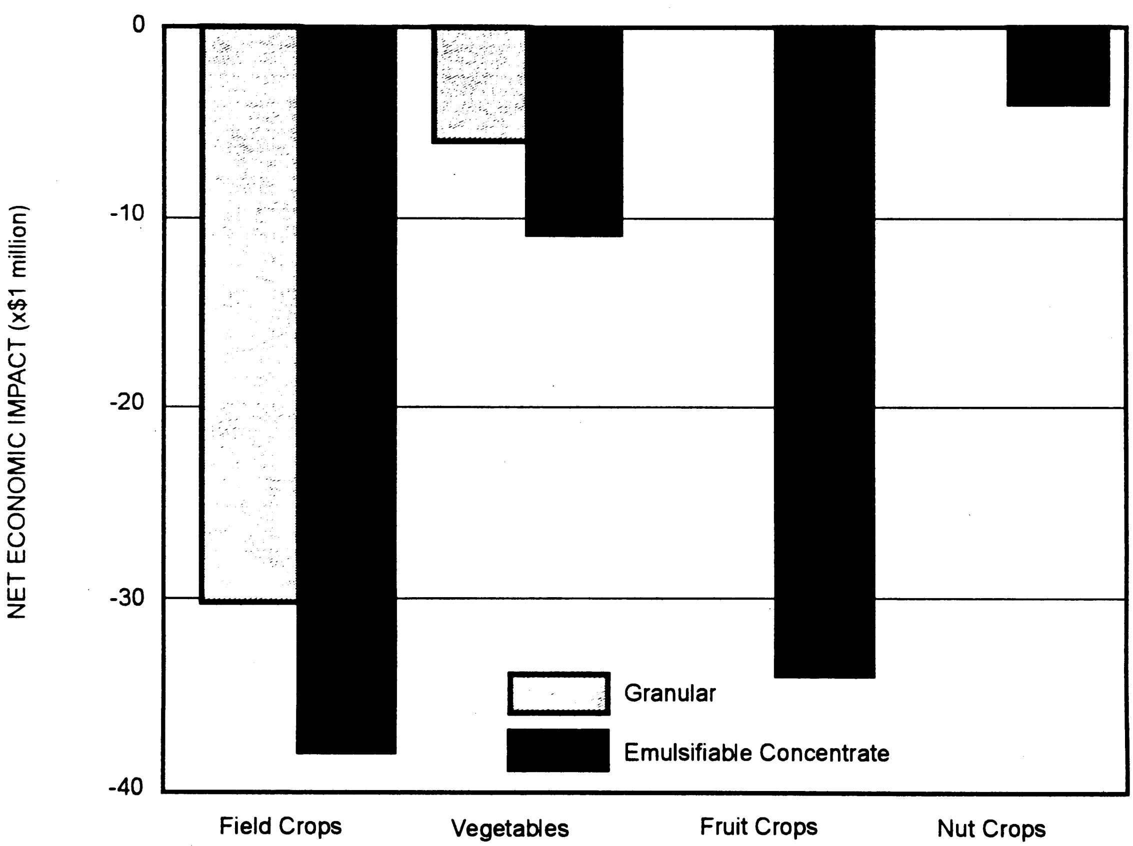


Table 1. Area planted, area treated, total use, and economic impacts associated with granular chlorpyrifos

Crop	Area Planted (x1,000 acres)	Area Treated (percent)	Area Treated (x1,000 acres)	Total Chemical Applied (x1,000 lb ai)	Change in Total Production (percent)	Net Economic Impact (x$1,000)
Field Crops						
Field Corn	68,738	10.0	6,907	8,079	([a])	[b]4,744
Peanut	1,630	37.9	619	1,110	-2.7	-30,333
Popcorn	268	5.5	15	17	0.0	4
Seed Corn	nda	nc	65	74	0.0	-10
Sorghum	11,580	1.3	154	144	0.0	-74
Soybean	59,230	0.1	41	41	([a])	-558
Sugarbeet	1,309	12.7	166	232	-0.3	-3,428
Tobacco	680	5.1	35	90	([a])	-637
Total			8,002	9,787		-30,292
Fruit						
Citrus	857	2.5	21	49	0	nc
Vegetables						
Broccoli	118	20.2	24	33	-0.2	-858
Brussels Sprout	4	90.0	3	8	-10.2	-1,563
Cabbage, Chinese	9	4.4	<1	<1	nda	-5
Cabbage, Head	73	9.3	7	7	-0.4	-723
Cauliflower	67	47.4	32	49	-0.4	-738
Collard	15	6.3	1	1	nda	-166
Kale	6	6.5	<1	<1	nda	-37
Onion	134	9.4	13	28	-0.2	-766
Radish	46	18.5	8	16	nda	-1,038
Rutabaga	nda	nc	<1	1	0.0	1
Sweet Corn	676	3.7	25	32	([a])	-42
Sweetpotato	90	11.9	11	22	-0.4	-642
Turnip	10	6.0	<1	1	0.0	3
Total			125	200		-6,574
TOTAL			8,148	10,036		-36,866

[a]Change of less than 0.1 percent.
[b]In addition, growers may lose unquantified benefits from broad-spectrum control, compatibility with urea sulfonyl herbicides, and safety associated with chlorpyrifos. The impact on corn should be viewed as an insignificant loss.

nda = no data available; nc = not calculated.

Table 2. Area planted, area treated, total use, and economic impacts associated with sprayable formulations of chlorpyrifos

Crop	Area Planted (x1,000 acres)	Area Treated (percent)	Area Treated (x1,000 acres)	Total Chemical Applied (x1,000 lb ai)	Change in Total Production (percent)	Net Economic Impact (x$1,000)
Field Crops						
Alfalfa	26,041	8.8	2,299	1,777	-0.7	-28,900
Clover	nda	nc	9	5	nda	-432
Cotton	11,158	12.9	1,442	1,433	-0.1	-4,609
Field Corn	68,738	2.1	1,447	1,515	([a])	[b] - 315
Grass Seed	nda	nc	57	55	nda	-2,100
Peanut	1,630	0.4	7	14	-0.0	-52
Popcorn	268	3.5	9	12	0.0	6
Seed Corn	nda	nc	17	22	0.0	31
Sorghum	11,580	10.8	1,251	841	0.0	-212
Soybean	59,230	3.5	2,097	1,136	([a])	2,014
Sugarbeet	1,309	11.7	153	131	-0.2	-1,901
Sunflower, Confect.	317	3.0	10	5	([a])	-27
Sunflower, Oil	1,590	3.4	53	30	([a])	46
Tobacco	680	21.2	144	362	0.1	-303
Wheat	69,324	2.8	1,953	977	([a])	-742
Total			10,948	8,315		-37,496
Fruit Crops						
Apple	462	40.8	188	374	-0.6	-9,063
Citrus	857	39.2	336	955	0.0	-5,750
Cranberry	27	38.2	10	21	-5.6	-9,529
Grape	759	1.9	14	20	([a])	-182
Nectarine	24	20.0	5	10	0.0	-214
Peach	185	41.8	77	72	0.0	-1,635
Pear	69	21.4	15	15	0.0	-273
Plum/Prune	127	7.8	10	20	([a])	-429
Strawberry	47	10.0	5	7	-0.6	-7,072
Total			660	1,494		-34,147
Nut Crops						
Almond	409	10.0	41	82	0.0	-381
Filbert	26	73.8	19	39	-0.7	20
Pecan	nda	nc	272	359	0.0	-57
Walnut	175	60.0	105	420	0.0	-3,568
Total			437	900		-3,986
Vegetables						
Asparagus	103	21.3	22	42	-0.6	-729
Broccoli	118	13.8	16	28	([a])	217
Brussels Sprout	4	100.0	4	15	-5.7	-805
Cabbage, Chinese	9	14.9	1	8	nda	11
Cabbage, Head	73	39.8	29	67	-0.9	-1,541
Cauliflower	67	36.1	24	37	0.2	494
Collard	15	2.1	<1	<1	nda	-3
Kale	6	8.3	<1	1	nda	-38
Kohlrabi	nda	nc	<1	<1	nda	-9
Mint	107	33.9	36	68	-6.3	-5,582
Onion	134	11.8	16	18	([a])	-198
Radish	46	4.0	2	3	nda	-572
Rutabaga	nda	nc	<1	<1	0.0	-1
Sweet Corn	676	6.3	42	107	([a])	-240
Sweetpotato	90	36.0	32	66	-0.9	-1,629
Turnip	10	6.0	<1	1	0.0	-1
Total			229	460		-10,626
TOTAL			12,274	11,169		-86,255

[a]Change of less than 0.1 percent.
[b]In addition, growers may lose unquantified benefits from broad-spectrum control, compatibility with sulfonyl urea herbicides, and safety associated with chlorpyrifos. The impact on corn should be viewed as an insignificant loss.

Introduction

The U.S. Environmental Protection Agency requested NAPIAP to conduct a biologic and economic assessment of selected formulations of the insecticide chlorpyrifos.

The following chlorpyrifos assessment report was prepared and edited by the staff of the National Agricultural Pesticide Impact Assessment Program (NAPIAP). Commodity authors, who are experts in their respective fields, wrote the chapters for this assessment. These authors were selected from a nationwide team of scientists who are involved with USDA.

The purpose of this report is to provide detailed information and analysis pertaining to the uses of chlorpyrifos in U.S. agriculture; to describe the benefits of those uses to agricultural productivity; to identify alternatives to chlorpyrifos; and to document the economic impacts of the usage of chlorpyrifos—as well as to predict the economic ramifications should this product be discontinued.

The commodity chapters in this assessment are presented alphabetically. The first chapter is an economic assessment prepared by NAPIAP's economists.

Assessment Methodology

The NAPIAP staff formed a nationwide team of scientists and representatives to conduct the assessment of chlorpyrifos usage and to estimate the potential impact on U.S. agriculture should its use be discontinued. Members of the assessment team were selected on the basis of their expertise in insect pest management on a specific commodity. The assessment team developed the survey instrument that was distributed to selected scientists in each State and territory that reported significant usage of chlorpyrifos.

Voids in survey data necessitated consulting experts when empirical data for insecticide use, effectiveness of pest control options, and yield and/or quality were not available. The authors made an effort to accurately portray each use of chlorpyrifos and to tie these uses directly to empirical data whenever possible. It was difficult to obtain insecticide use data and insecticide performance data regarding certain small-acreage commodities (e.g., asparagus and rutabaga). Additionally, it was difficult for authors to find insecticide screening trials that compared chlorpyrifos with alternatives and also included yield data. In crops where no yield data were available, experts were consulted for estimates of pesticide usage.

Any discussions concerning the future of chlorpyrifos formulations, particularly the granules, must be viewed in the context of the present reregistration process. It is becoming increasingly difficult to estimate the continued availability and future costs of alternative insecticides and formulations that have entered or soon will enter the reregistration process.

Characteristics and Usage Patterns of Chlorpyrifos

Chlorpyrifos is a moderately toxic, broad-spectrum insecticide used to control a variety of crop pests. All formulations containing chlorpyrifos studied in this assessment are General Use insecticides. The following formulations are available for use in American agriculture under the trade name Lorsban: 15 percent granular; 4 lb per gal emulsifiable concentrate; and 50 percent wettable powder. Chemically, chlorpyrifos is (0,0-Diethyl-0-(3,5,6-trichloro-2-pyridyl) phosphorothioate. Chlorpyrifos is also available in formulations for household, nursery, greenhouse, and turf usage under the trade name Dursban. Uses of Dursban formulations are not covered in this assessment. The nursery, greenhouse, and turf uses of chlorpyrifos are covered in a separate assessment that will be published shortly after this assessment.

The physical, chemical, and toxicological characteristics, mode of action, environmental effects, safety to wildlife, and such related information pertaining to chlorpyrifos are beyond the scope of, and not the purpose of, this assessment report. However, there are adequate descriptions of these topics in the Extension Toxicology Network (Extoxnet), DowElanco's Material Safety Data Sheet, chlorpyrifos 4E, 15G, and 50W labels (6/8/90), and the Chlorpyrifos Insecticide Technical Bulletin (Form No. 134-337-87).

Chlorpyrifos was originally registered in 1965. Its initial agricultural use was in California in 1969. The first federally labeled agricultural uses were issued in 1974 for control of corn rootworm larvae and peachtree borer and as a seed treatment on field corn. Today, the major agricultural use of chlorpyrifos is on corn (Figure 1). Other registered agricultural uses of this chemical in agriculture include: alfalfa, almond, apple, asparagus, banana (import tolerance), blueberry, bean, cherry, cucumber, cole crops, citrus fruits, corn, cotton, cottonseed, cranberry, date, fig, filbert, grape, kiwi fruit (import tolerance), leek, mint, nectarine, onion, peach, peanut, pear, pecan, pepper, plum/prune, radish, rappini, rutabaga, seed treatments, grain sorghum, soybean, strawberry, sugar beet, sunflower, sweetpotato, tobacco, tomato, turnip, and walnut. Additional registrations include: (1) uncultivated agricultural areas, (2) noncrop areas, and (3) nonfood crop use on commercial sod and nursery grass sod, ornamental lawns, golf course turf, ornamental turf, and turfgrass grown for seed.

Supplemental labels (Section 24C or Section 18) for Lorsban formulations of chlorpyrifos are current in South Dakota, Maryland, California, Colorado, Texas, Alabama, Arizona, Montana, Kansas, Oregon, Wyoming, Nebraska, Oklahoma, Washington, Idaho, Mississippi, Michigan, Delaware, Missouri, Pennsylvania, Georgia, Florida, Tennessee, and Arkansas. Crops listed on supplemental labels include: wheat, alfalfa, tree nuts, cotton, asparagus, cole crops, vegetable crops, sugar beet, grape, onion, sweet and field corn, perennial grass seed crops, carrot, radish, mint, strawberry, clover seed production, peanut, leafy vegetables, pepper, and tomato.

Pests controlled under all registered label uses include leaf-feeding insects, spider mites, and soil insects. For a complete list of the extensive number of insects controlled by chlorpyrifos, see current Federal and State labeling.

Short-Run Economic Impacts of Canceling Chlorpyrifos

Martin Shields and Craig Osteen

The conclusions in this document concerning both the usage of chlorpyrifos, in its granular and sprayable formulations, and the economic impacts if registrations for this insecticide are canceled, are based on estimates compiled by the 1991 National Agricultural Pesticide Impact Assessment Program (NAPIAP) chlorpyrifos assessment team.

Economic impact predictions are based on estimates of: (1) the current usage of chlorpyrifos, (2) usage of alternative insecticides if the registration of granular or sprayable formulations of chlorpyrifos are canceled, and (3) changes in yield and per acre treatment costs that would result from the use of these alternatives.

Economic impacts include both producer and consumer impacts as well as the net economic impact. Producer impact is the change in net producer income based on changes in crop price, output, and treatment costs. Treatment costs consist of the per acre costs of pesticides and/or nonchemical management practices and the associated costs of application. Consumer impact approximates the change in consumer surplus, accounting for the economic effect of price changes and the quantity consumed. This approximation assumes a linear demand function. Net economic impact is the sum of producer and consumer impacts, and serves as a measure of the efficiency impact associated with cancellation of a registration.

The economic estimates presented below are valid only in the short run since they do not address acreage or other input adjustments in response to changes in price, yield, and costs. Economic effects were computed as follows:

Change in farm-level commodity price: $N = X/E$

where

- N = percent change in farm-level commodity price
- E = price elasticity of demand (% change quantity/% change price)
- X = percent reduction in U.S. output

Total change in production cost: $C = D(A_t/100)(A_p)$

where

- C = change in total production cost (\$)
- D = change in production cost per treated acre (\$/acre)
- A_t = percentage of planted acres treated with the assessed pesticide
- A_p = acres planted

Change in net producer revenue: $CR = (P_aQ_a)-(P_bQ_b)-C$

where

- CR = change in net producer revenue (\$)
- P_b = average market price before assessed pesticide is canceled (\$/unit)
- Q_b = commodity production before assessed pesticide is canceled (\$/unit)
- P_a = $P_b(1+N/100)$
- Q_a = $Q_b(1-x/100)$ = commodity production after assessed pesticide is canceled

Consumer Impact: $CI = (P_a-P_b)(Q_a+Q_b)/2$

where

- CI = consumer impact (\$)

For crops where elasticities are not available or where yield impacts are small, the economic impact is computed as the value of yield loss, assuming a constant price, plus cost change. When elasticities are not available, price changes, consumer effects, and producer effects cannot be estimated.

For some crops, production and price data are not regularly available from USDA. When available, acreage and value of production data from the *1987 Census of Agriculture* were used to compute value losses.

Accuracy of the Results

There is a degree of uncertainty in the estimates of economic impacts. Many of the reported levels of pesticide use and the choices and efficacy of alternative practices are based on expert judgment. Pesticide prices utilized in the study are based on published sources and information from registrants, which may not be the precise prices paid by farmers. Many of the application rates used are recommended rates, and may not be the precise farm level application rates. Unlike chlorpyrifos, some chemical alternatives are classified as Restricted Use, and some farmers may be required to undergo training in order to apply them. In some cases, equipment modifications would be required. As a result, estimates of changes in cost per treated acre could vary from actual changes by several dollars. Price elasticities used to compute price changes and welfare effects are obtained from published sources. However, elasticities from different studies often vary widely, and elasticities employed in this study are usually in the middle of a very broad range. The greatest impact of elasticity choice on the economic assessment will be on the estimated price change and the subsequent distribution of impacts between consumers and producers. The effect of elasticity choice on the net economic effect will be minimal. There is no statistical measure of the accuracy or precision of the economic estimates. However, the economic estimates are the best available from information collected and should have the correct order of magnitude.

General Versus Restricted Use Pesticides

Chlorpyrifos is registered as a General Use insecticide and thus requires no special licensing by the applicator. In contrast, many of the alternatives are Restricted Use pesticides, which may be applied only after the applicator undergoes formal training in proper handling and application. One obvious economic benefit of the use of a General Use pesticide is that there is no need to pay to undergo the training. Less obvious is the notion that farmers *may* perceive a General Use pesticide to be safer to handle than a Restricted Use pesticide. As a result, farmers may be willing to pay more for a General Use insecticide that performs with the same efficacy as an alternative pesticide that is restricted. A study by DowElanco, which was not validated by NAPIAP, indicates that the perceived safety benefits of chlorpyrifos 15G could exceed $1 per acre to corn producers (Bacon, 1993).

Estimated Economic Impacts

The economic impacts of the cancellation of chlorpyrifos on the specific crops presented below are summarized in Tables 3 through 8. Tables 3 and 4 provide acreage, production, and chemical application rates for flowable and granular formulations respectively. Tables 5 and 6 indicate impacts of cancellation on output levels and production costs. Tables 7 and 8 provide the estimated impacts of cancellation on price, producer revenues, consumer expenditures, and the general economy.

Field Crops

Approximately 10.9 million acres of field crop production in the United States are treated with sprayable formulations of chlorpyrifos, accounting for nearly 8.3 million lb a.i. applied annually. Should the registration of sprayable formulations of chlorpyrifos be canceled for all field crops, the net economic impact would be a $37 million loss to the economy.

Nearly 9.8 million lb a.i. of chlorpyrifos 15G are applied to 8.0 million acres of field crop production. Cancellation of chlorpyrifos 15G for all field crops would result in a loss of $30 million to the economy.

Alfalfa—Chlorpyrifos 4E is applied to 2.3 million acres (9 percent) of alfalfa in the United States, accounting for 1.8 million lb a.i. If chlorpyrifos 4E is canceled, carbofuran—a Restricted Use pesticide—would be the primary alternative. Other alternatives are less efficacious.

In Idaho, no effective alternative for chlorpyrifos 4E is currently registered for control of redbacked cutworm in alfalfa. Entomologists indicate that yield losses on untreated acreage would be 90 percent. Up to 25 percent (250,000 acres) of Idaho's alfalfa acreage may be infested by redbacked cutworm, although infestation occurs, on the average, only 3 years out of 10.

To correctly estimate the economic implications of cancellation requires investigating two possible scenarios: the years with no redbacked cutworm infestation in Idaho, and the years where the insect can have a major economic impact on State production. In both instances, treatment costs will decrease less than $2 per treated acre.

When there is no infestation in Idaho, cancellation of chlorpyrifos 4E would result in a $23.4 million loss to the economy. This is attributed primarily to a decrease in yield of nearly 3 percent on all treated acreage. The effect on national production would be a loss of less than 1 percent, and prices would not change.

The impact of cancellation under heavy redbacked cutworm infestation in Idaho is much more pronounced. Production losses on all treated acreage would average nearly 5 percent, and total production would decline almost 1 percent. The net economic effect would be a loss of approximately $41.8 million. Due to the absence of elasticity data, the distribution of the impact amongst producers and consumers could not be determined.

Combining the above scenarios and projecting over 10 years, annual losses would average $28.9 million.

Impacts of cancellation would be most severe for growers in Idaho in years of infestation. For farmers who grow alfalfa to feed their livestock, operating costs would increase by the amount spent on purchasing feed from elsewhere. If the infestation is regional, trucking costs could further increase prices. The above estimate does not take into account increases in production in other regions as a response to meet the market demand.

Clover seed—Approximately 4,500 lb a.i. of chlorpyrifos 4E are applied to 9,000 acres of red clover seed production. The use of alternative pest management measures would increase per acre treatment costs by more than $14, for a total increase of $130,000, while production losses on treated acreage would be 10 percent. The primary chemical alternative, oxydemeton-methyl, is a Restricted Use pesticide. The net economic impact of cancellation would be a loss of more than $432,000. Since there are no estimates of elasticity, the distribution of this loss amongst producers and consumers could not be determined.

Cotton—Chlorpyrifos 4E is applied to 1.4 million acres (13 percent) of cotton in the United States, accounting for 1.4 million lb a.i. If chlorpyrifos 4E were canceled, cotton yields on treated acreage would decrease less than 1 percent. Due to higher insecticide expenditures, production costs would increase by more than $3 per acre on currently treated acreage. The cancellation of chlorpyrifos 4E would not significantly affect the market price of cotton. The net economic effect of cancellation would be a $4.6 million loss, borne entirely by cotton producers.

Field corn—Chlorpyrifos 4E is applied to approximately 1.4 million acres (2 percent) of field corn in the United States, accounting for 1.5 million lb a.i. Should chlorpyrifos 4E be canceled, field corn yields would be reduced by less than 1 percent on treated acreage. The impact on total production would be insignificant; therefore, prices would not change. Production costs would decrease approximately $1 per acre on acreage currently treated with chlorpyrifos 4E. Cancellation of chlorpyrifos 4E would result in a net gain of $300,000, or less than $1 per treated acre.

Approximately 6.9 million acres (10 percent) of field corn production are treated with 8.1 million lb a.i. of chlorpyrifos 15G. If chlorpyrifos 15G is canceled, total production would increase slightly, since alternative insecticides offer similarly effective pest management (Nebraska reports that alternatives perform slightly better against corn rootworm larvae). Market price would not be affected. Production costs on acreage currently treated with chlorpyrifos 15G would remain

Table 3. Sprayable formulations of chlorpyrifos (4E and 50WP) usage in U.S. agriculture, 1987-89

Crop	Area Planted (x1,000 acres)	Average Production (x1,000)	Production Unit	Average Market Price (dollars)	Area Treated (percent)	Treatment Rate (lb ai/acre)	Total Chemical Applied (x1,000 lb ai)
Field Crops							
Alfalfa	26,041	76,912	Tons	91.50	8.8	0.7	1,777
Clover Seed	nda	nda	Pounds	0.75	nc	0.5	5
Cotton	11,158	14,135	Bales	0.62	12.9	1.0	1,433
Field Corn	68,738	6,529,044	Bushels	2.28	2.1	1.0	1,515
Grass Seed	nda	nda		nc	nc	1.0	55
Peanut	1,630	3,875,659	Pounds	0.28	0.4	2.0	14
Popcorn	268	838,852	Pounds	nda	3.5	1.3	12
Seed Corn	nda	nda	Bushels	66.83	nc	1.3	22
Sorghum	11,580	23,258	Tons	72.27	10.8	0.8	841
Soybean	59,230	1,804,456	Bushels	6.32	3.5	0.5	1,136
Sugarbeet	1,309	26,145	Tons	40.50	11.7	0.5	131
Sunflower, Confection	317	3,327	CWT	12.83	3.0	0.5	5
Sunflower, Oil	1,590	17,311	CWT	9.07	3.4	0.6	30
Tobacco	680	1,324,182	Pounds	1.69	21.2	2.5	362
Wheat	69,324	1,985,235	Bushels	3.33	2.8	0.5	977
Total							8,315
Fruit Crops							
Apple	462	9,959,967	Pounds	0.15	40.8	2.0	374
Citrus	857	275,602	Boxes	9.10	39.2	2.8	955
Cranberry	27	3,769	Barrels	44.73	38.2	2.1	21
Grape	759	5,732	Tons	271.66	1.9	1.5	20
Nectarine	24	197	Tons	378.00	20.0	2.0	10
Peach	185	2,442,933	Pounds	0.21	41.8	1.0	72
Pear	69	903	Tons	249.66	21.4	1.0	15
Plum/Prune	127	472	Tons	176.30	7.8	2.0	20
Strawberry	47	11,357	CWT	55.50	10.0	1.1	7
Total							1,494
Nut Crops							
Almond	409	580,000	Pounds	1.02	10.0	2.0	82
Filbert	26	17	Tons	816.00	73.8	2.0	39
Pecan	nda	273,633	Pounds	0.60	nc	1.3	359
Walnut	175	228	Tons	992.00	60.0	3.8	420
Total							900
Vegetables							
Asparagus	103	2,421	CWT	69.10	21.3	1.9	42
Broccoli	118	12,605	CWT	21.33	13.8	1.8	28
Brussels Sprout	4	480	CWT	33.00	100.0	3.2	15
Cabbage, Chinese	9	nda		nda	14.9	5.6	8
Cabbage, Head	73	18,542	CWT	9.49	39.8	2.3	67
Cauliflower	67	7,698	CWT	25.67	36.1	1.5	37
Collard	15	nda	CWT	nda	2.1	1.7	<1
Kale	6	nda	Pounds	0.20	8.3	2.0	1
Kohlrabi	nda	nda	Pounds	nda	nc	1.6	<1
Mint	107	7,386	Pounds	13.40	33.9	1.9	68
Onion	134	46,581	CWT	11.22	11.8	1.2	18
Radish	46	nda	Pounds	3.9	4.0	1.4	3
Rutabaga	nda	nda	CWT	20.88	nc	2.1	<1
Sweet Corn	676	70,244	CWT	14.87	6.3	2.0	107
Sweetpotato	90	11,305	CWT	13.67	36.0	2.0	66
Turnip	10	nda	Tons	nda	6.0	1.1	<1
Total							460
TOTAL							11,169

nda = no data available; nc = not calculated

Table 4. Chlorpyrifos 15G usage in U.S. agriculture, 1987-89

Crop	Area Planted *(x1,000 acres)*	Average Production *(x1,000)*	Production Unit	Average Market Price *(dollars)*	Area Treated *(percent)*	Treatment Rate *(lb ai/ac)*	Total Chemical Applied *(x1,000 lb ai)*
Field Crops							
Field Corn	68,738	6,529,044	Bushels	2.28	10.0	1.2	8,079
Peanut	1,630	3,875,659	Pounds	0.28	37.9	2.8	1,110
Popcorn	268	838,852	Pounds	nda	5.5	0.8	17
Seed Corn	nda	nda		66.83	nc	1.1	74
Sorghum	11,580	23,258	Tons	72.27	1.3	0.9	144
Soybean	59,230	1,804,456	Bushels	6.32	0.1	1.0	41
Sugarbeet	1,309	26,145	Tons	40.50	12.7	1.4	232
Tobacco	680	1,324,182	Pounds	1.69	5.1	2.6	90
Total							9,787
Fruit							
Citrus	857	275,602	Boxes	9.10	2.5	2.3	49
Vegetables							
Broccoli	118	12,605	CWT	21.33	20.2	1.4	33
Brussels Sprout	4	nda	CWT	33.00	90.0	2.7	8
Cabbage, Chinese	9	nda	CWT	nda	4.4	1.3	<1
Cabbage, Head	73	18,542	CWT	9.49	9.3	1.2	7
Cauliflower	67	7,698	CWT	25.67	47.4	1.6	49
Collard	15	nda	CWT	nda	6.3	0.8	1
Kale	6	nda	Pounds	0.20	6.5	1.2	<1
Onion	134	46,581	CWT	11.22	9.4	2.3	28
Radish	46	nda	Pounds	nda	18.5	1.9	16
Rutabaga	nda	nda	CWT	20.88	nc	2.3	1
Sweet Corn	676	70,244	CWT	14.87	3.7	1.3	32
Sweetpotato	90	11,305	CWT	13.67	11.9	2.1	22
Turnip	10	nda	Tons	20.00	6.0	1.6	1
Total	1,248						200
TOTAL							10,036

nda = no data available; nc = not calculated

essentially unchanged—a decrease of about 20 cents per acre. The net economic impact of cancellation would be a gain of $4.7 million, or less than $1 per treated acre. Of this gain, $1.3 million would be attributed to slightly lower pesticide expenditures. The remainder is attributed primarily to the increased yield in Nebraska, which was obtained by using alternative measures of controlling corn rootworm larvae.

There are several difficult-to-quantify reasons why farmers may use granular chlorpyrifos even though the economic analysis shows no benefits. First, the slight per acre decrease in production costs is essentially zero. Second, chlorpyrifos is, and has been marketed as, a broad-spectrum insecticide, capable of controlling a variety of pests. Thus, according to the manufacturer, farmers who treat for one pest (such as rootworm) are getting control of other pests (such as cutworms). Therefore, farmers may be receiving pest control or insurance benefits not accounted for in this assessment. Third, because chlorpyrifos 15G and 4E are General Use pesticides (not Restricted Use), farmers do not need special certification to apply them. As a result, farmers may perceive a safety benefit. Finally, chlorpyrifos is compatible with new sulfonyl urea herbicides, while some alternatives are not. A study by DowElanco, which has not been validated by NAPIAP, indicates that such attributes as safety to humans, broad-spectrum control, and compatibility with sulfonyl urea herbicides could each be worth more than $1 per acre to corn growers (Bacon, 1993). If so, the value of these attributes of chlorpyrifos could exceed the pest control gains from using alternatives, and therefore would justify chlorpyrifos use.

In a more general sense, the economic loss caused by withdrawing any single soil insecticide used on corn, such as chloryrifos, will be relatively small because a variety of effective alternative materials are available. However, the 1983 NAPIAP corn and soybean assessment showed that the overall value of controlling soil insects could be very high. The study estimated that U.S. corn production would decrease by 9 percent if soil insecticides were no longer used and crop rotation was not used as an alternative (Osteen and Kuchler, 1984). The economic loss was estimated to be $2.1 billion (Osteen and Kuchler, 1986). As a result, if the registrations of soil insecticides were sequentially canceled, the last available material would have much higher benefits than if it were the first material removed from the market, even if the comparative performance of the materials did not change.

Table 5. Estimated change in crop production if sprayable formulations of chlorpyrifos (4E and 50WP) are replaced by alternative pest control measures

Crop	Change in Total Production *(percent)*	Change in Total Production *(x1,000)*	Production Unit	Change in Production Cost *(dollars/acre)*	Total Change in Production Cost *(x$1,000)*
Field Crops					
Alfalfa	-0.7	-506	Tons	-1.74	-4,000
Clover Seed	nda	-403	Pounds	14.41	130
Cotton	-0.1	-14	Bales	3.19	4,600
Field Corn	([a])	-541	Bushels	-1.07	-1,548
Grass Seed	nda	nda		-10.00	-573
Peanut	-0.0	-207	Pounds	-0.81	-6
Popcorn	0.0	0	Pounds	-0.63	-6
Seed Corn	0.0	0	Bushels	-1.82	-31
Sorghum	0.0	0	Bushels	0.17	212
Soybean	([a])	-123	Bushels	-1.33	-2,791
Sugarbeet	-0.2	-50	Tons	-0.75	-115
Sunflower, Confection	([a])	0	CWT	2.84	27
Sunflower, Oil	([a])	4	CWT	-0.16	-9
Tobacco	0.1	1,029	Pounds	14.19	2,043
Wheat	([a])	-756	Bushels	-0.91	-1,777
Total					-3,844
Fruit Crops					
Apple	-0.6	-55,432	Pounds	3.46	650
Citrus	0.0	0	Boxes	14.45	4,851
Cranberry	-5.6	-212	Barrels	5.26	54
Grape	([a])	-1	Tons	-11.40	-161
Nectarine	0.0	0	Tons	44.30	214
Peach	0.0	0	Bushels	11.92	917
Pear	0.0	0	Tons	18.46	273
Plum/Prune	([a])	-2	Tons	9.80	98
Strawberry	-0.6	-83	CWT	1.65	2,379
Total					9,275
Nut Crops					
Almond	0.0	0	Pounds	9.32	381
Filbert	-0.7	<-1	Tons	-4.41	-86
Pecan	0.0	0	Pounds	0.21	57
Walnut	0.0	0	Tons	33.99	3,568
Total					3,920
Vegetables					
Asparagus	-0.6	-14	CWT	-10.32	-227
Broccoli	([a])	+4	CWT	-7.60	-121
Brussels Sprout	-5.7	-28	CWT	-22.94	-109
Cabbage, Chinese	nda	nda	CWT	-15.16	-20
Cabbage, Head	-0.9	-158	CWT	1.42	41
Cauliflower	0.2	18	CWT	-0.88	-21
Collard	nda	-10	CWT	8.75	3
Kale	nda	-201	Pounds	-3.79	-2
Kohlrabi	nda	-2,215	Pounds	-4.12	0
Mint	-6.3	-462	Pounds	-16.90	-614
Onion	([a])	-14	CWT	2.50	40
Radish	nda	-310	Pounds	4.48	8
Rutabaga	0.0	0	CWT	3.00	<1
Sweet Corn	([a])	-1	CWT	4.37	233
Sweetpotato	-0.9	-104	CWT	6.36	206
Turnip	0.0	0	Tons	2.34	1
Total					-582
TOTAL					8,769

[a]Change of less than 0.1 percent

nda = no data available

Table 6. Estimated change in crop production if chlorpyrifos 15G is replaced by alternative pest control measures

Crop	Change in Total Production *(percent)*	Change in Total Production *(x1,000)*	Production Unit	Change in Production Cost *(dollars/acre)*	Total Change in Production Cost *(x$1,000)*
Field Crops					
Field Corn	([a])	1,505	Bushels	-0.19	-1,310
Peanut	-2.7	-103,275	Pounds	1.26	774
Popcorn	0.0	0	Pounds	-0.28	-6
Seed Corn	0.0	0	Bushels	0.15	10
Sorghum	0.0	0	Bushels	0.48	74
Soybean	([a])	-101	Bushels	-1.96	-81
Sugarbeet	-0.3	-80	Tons	1.05	174
Tobacco	([a])	-250	Pounds	6.24	214
Total					-151
Fruit					
Citrus	0	0	Boxes	-0.98	-21
Vegetables					
Broccoli	-0.2	-29	CWT	10.31	245
Brussels Sprout	-10.2	-49	CWT	-17.14	-52
Cabbage, Chinese	nda	nda	CWT	6.16	2
Cabbage, Head	-0.4	-71	CWT	7.30	46
Cauliflower	-0.4	-29	CWT	-0.47	-15
Collard	nda	-32	CWT	4.09	5
Kale	nda	-160	Pounds	11.65	5
Onion	-0.2	-73	CWT	-4.74	-60
Radish	nda	0	Tons	-0.74	-6
Rutabaga	0.0	0	CWT	-3.33	-1
Sweet Corn	([a])	-1	CWT	1.03	25
Sweetpotato	-0.4	-43	CWT	5.63	60
Turnip	0.0	0	CWT	-5.27	-3
Total					251
TOTAL					79

[a]Change of less than 0.1 percent

nda = no data available

Popcorn—Chlorpyrifos 4E is applied to approximately 9,000 acres (4 percent) of popcorn. This accounts for 12,000 lb a.i. Should chlorpyrifos 4E be canceled, the use of lower priced alternatives would cause costs to decrease by less than $1 per treated acre, while yield would remain unchanged. The net economic impact of cancellation would be a gain of $6,000, or less than $1 per treated acre.

Chlorpyrifos 15G is applied to approximately 15,000 acres (6 percent) of popcorn, accounting for 17,000 lb a.i. Cancellation of chlorpyrifos 15G would cause costs to decrease less than $1 per treated acre, as alternatives are competitively priced. Production levels would remain unchanged due to equal efficacy of available alternatives. As a result, popcorn prices would not be affected. Due to reduced pesticide expenditures, cancellation would result in a $4,000 net gain to the economy.

Seed corn—Chlorpyrifos 4E is applied to more than 17,000 acres of seed corn production. This accounts for 22,000 lb a.i. Should chlorpyrifos 4E be canceled, the use of alternative pest management measures would decrease per acre treatment costs by $2 per acre, while production would be unchanged. In the event of cancellation, the net economic impact would be a gain of $31,000.

Chlorpyrifos 15G is applied to approximately 65,000 acres of seed corn, accounting for 74,000 lb a.i. In the event of cancellation, the use of alternative measures would increase production costs by less than $1 per acre, while output would remain unchanged. The net economic impact would be a $10,000 loss to the economy, borne entirely by producers through higher pesticide expenditures.

Grass seed—Approximately 57,000 acres of grass seed production are treated with 55,000 lb a.i. of chlorpyrifos 4E. National acreage and production figures are not available. All reported usage of chlorpyrifos 4E on grass seed is in Idaho, Oregon, and Washington, primarily to control cutworms. No effective substitute is currently registered for cutworms. Not treating acreage would reduce production costs $10 per acre. Cancellation of chlorpyrifos 4E would lead to substantial reductions in production levels on infested acreage. For instance, yield losses on heavily infested acreage in Idaho

Table 7. Economic impact on U.S. agriculture if sprayable formulations of chlorpyrifos are replaced by alternative pest control measures

Crop	Change in Price (percent)	Change in Net Revenue (x$1,000)	Consumer Impact (dollars)	Net Economic Impact (x$1,000)
Field Crops				
Alfalfa	nc	nc	nc	-28,900
Clover Seed	nc	nc	nc	-432
Cotton	0	-4,609	0	-4,609
Field Corn	0	315	0	[a]315
Grass Seed	nc	nc	nc	-2,100
Peanut	0	-52	0	-52
Popcorn	0	6	0	6
Seed Corn	0	31	0	31
Sorghum	0	-191	0	-212
Soybean	0	2,014	0	2,014
Sugarbeet	1	6,456	-8,357	-1,901
Sunflower, Confection	0	-27	0	-27
Sunflower, Oil	0	46	0	46
Tobacco	0	-304	0	-303
Wheat	0	-749	0	-742
Total				-36,866
Fruit Crops				
Apple	2	25,484	-34,547	-9,063
Citrus	0	-5,750	0	-5,750
Cranberry	nc	nc	nc	-9,529
Grape	0	-182	0	-182
Nectarine	0	-214	0	-214
Peach	nc	nc	nc	-1,635
Pear	0	-273	0	-273
Plum/Prune	0	-429	0	-429
Strawberry	3	12,175	-19,248	-7,072
Total				-34,147
Nut Crops				
Almond	0	-381	0	-381
Filbert	0	20	0	20
Pecan	0	-61	0	-57
Walnut	0	-3,866	0	-3,568
Total				-3,986
Vegetables				
Asparagus	nc	nc	nc	-729
Broccoli	0	217	0	217
Brussels Sprout	nc	nc	nc	-805
Cabbage, Chinese	nc	nc	nc	11
Cabbage, Head	0	-1,521	0	-1,541
Cauliflower	0	494	0	494
Collard	0	-3	0	-3
Kale	0	-38	0	-38
Kohlrabi	nc	nc	nc	-9
Mint	nc	nc	nc	-5,582
Onion	0	-198	0	-198
Radish	nc	nc	nc	-572
Rutabaga	0	-1	0	-1
Sweet Corn	0	-240	0	-240
Sweetpotato	nc	nc	nc	-1,629
Turnip	0	-1	0	-1
Total				-10,626
TOTAL				85,625

[a]Growers may lose unquantified benefits from broad-spectrum control, compatibility with sulfonyl urea herbicides, and safety associated with chlorpyrifos. The impact on corn should be viewed as an insignificant loss.

nc = not calculated

Table 8. Economic impact on U.S. agriculture if chlorpyrifos 15G is replaced by alternative pest control measures

Crop	Change in Price (percent)	Change in Net Revenue (x$1,000)	Consumer Impact (x$1,000)	Net Economic Impact (x$1,000)
Field Crops				
Field Corn	0	4,744	0	[a]4,744
Peanut	4	17,214	-47,553	-30,339
Popcorn	0	4	0	4
Seed Corn	0	-10	0	-10
Sorghum	0	-74	0	-74
Soybean	0	-558	0	-558
Sugarbeet	1	10,025	-13,454	-3,428
Tobacco	0	-637	0	-637
Total				-30,292
Fruit				
Citrus	nc	nc	nc	nc
Vegetables				
Broccoli	nc	nc	nc	-858
Brussels Sprout	nc	nc	nc	-1,563
Cabbage, Chinese	nc	nc	nc	-5
Cabbage, Head	0	-301	-422	-723
Cauliflower	0	-738	0	-738
Collard	nc	nc	nc	-166
Kale	0	-37	0	-37
Onion	1	2,522	-3,288	-766
Radish	nc	nc	nc	-1,038
Rutabaga	0	1	0	1
Sweet Corn	0	-42	0	-42
Sweetpotato	nc	nc	nc	-642
Turnip	0	3	0	3
Total				-6,574
TOTAL				-36,866

[a]Growers may lose unquantified benefits from broad-spectrum control, compatibility with sulfonyl urea herbicides, and safety associated with chlorpyrifos. The impact on corn should be viewed as an insignificant loss.

nc = not calculated

could reach 60 percent. Many other fields would go out of production (Ron Burr, 1993, personal communication). Economic losses on such fields would be the difference between profits from grass seed production and profits accrued from alternative uses of the land. Severe infestation occurring mid-season could result in total loss of income from the field that year. Significant reductions in production would serve to increase the price of grass seed. Economic losses in Oregon without chlorpyrifos are estimated to be $900,000 due to cutworms and $800,000 to $1.2 million due to billbugs. Total economic impacts would be much more severe. Due to the absence of data on total production impacts of cancellation, net economic impacts of loss of chlorpyrifos in other States could not be calculated.

Peanut—Approximately 7,000 acres of peanut production (less than 1 percent) are treated with 14,000 lb a.i. of chlorpyrifos 4E. Cancellation would lead to a 1 percent reduction in peanut production on treated acreage. Changes in national production would be small, so peanut prices would not change significantly. Treatment costs would decrease less than $1 for each acre currently treated with chlorpyrifos 4E, because alternative treatments are less expensive. However, most listed alternatives are granular; therefore, farmers may be required to make equipment changes. The net short-run economic loss of cancellation would be $52,000, borne entirely by growers.

Chlorpyrifos 15G is applied to more than 619,000 acres (38 percent) of peanut in the United States. This accounts for an annual usage of more than 1.1 million lb a.i. The cancellation of chlorpyrifos 15G would result in a reduction in production of nearly 3 percent, and would raise the price of peanuts by more than 4 percent. Due to higher treatment costs associated with the alternatives, costs per treated acre of production would increase slightly more than $1. The economic impact of cancellation would be a $17.2 million increase in producer revenues and a $47.5 million loss to consumers. This results in a net economic loss of $30.3 million.

Sorghum—More than 1.3 million acres (11 percent) of U.S. sorghum are treated with chlorpyrifos 4E, accounting for 841,000 lb a.i. Should chlorpyrifos 4E be canceled, per acre treatment costs with alternative pest management methods would increase less than $1. Total production would not be affected, as alternatives provide equally efficacious crop protection. The net economic impact of cancellation would be a $212,000 loss attributed to slightly higher insecticide expenditures. In the short run, consumers would not be affected by cancellation.

Less than 2 percent (154,000 acres) of U.S. sorghum acreage is treated with chlorpyrifos 15G. This accounts for 144,000 lb a.i. applied annually. If chlorpyrifos 15G were canceled, the use of alternative pest management strategies would cause an increase of less than $1 in per acre treatment costs. The net economic impact of cancellation would be a $74,000 loss to the economy. This would be borne entirely by producers in the form of higher insecticide expenditures.

Soybean—Nearly 2.1 million acres (3.5 percent) of soybean acreage are treated in the United States with 1.1 million lb a.i. of chlorpyrifos 4E. Should chlorpyrifos 4E be canceled, alternative insect control measures are available. In some instances, the use of less efficacious alternatives to treat twospotted spider mite would cause yields to decrease up to 10 percent. Nationally, production would decrease less than 1 percent on treated acreage, while production costs would decrease about $1 per treated acre. The slight decrease in production would have no effect on the price of soybeans. The net impact of cancellation would be a $2 million (or about $1 per treated acre) gain to the economy, accrued entirely by producers.

Although the economic analysis indicates cancellation of chlorpyrifos 4E would cause an economic gain, its current use could be justified by several factors. Dimethoate 4E is the only effective substitute for chlorpyrifos 4E in controlling twospotted spider mite, a pest affecting a large share of the treated acreage. The price of dimethoate is lower than chlorpyrifos 4E, but supplies have been limited in the past. Given that losses caused by twospotted spider mite can approach 40 percent on infested acreage, farmers are willing to buy the more expensive insecticide. It should be noted, however, that the data presented above reflect, in part, an unusually severe and widespread outbreak of spider mite in 1988. Of the acreage reported treated with chlorpyrifos 4E, nearly 1.5 million were treated for twospotted spider mite. As a result, the reported expected economic gain may be overstated relative to normal conditions; excluding the mite problem, any economic impact may be insignificant.

Approximately 41,000 lb a.i. of chlorpyrifos 15G are applied to approximately 41,000 (less than 1 percent) acres of soybean production. Treated acreage is primarily in the Southern States. Should chlorpyrifos 15G be canceled, production costs would decrease nearly $2 per treated acre. This decrease is attributed to the absence of registered alternatives for the control of lesser cornstalk borer, which is the target pest on more than half the treated acreage. If chlorpyrifos 15G were unavailable, crop losses due to severe infestations of lesser cornstalk borer could cause farmers to either replant or face a yield reduction up to 70 percent. Production impacts would be most severe in Florida and Mississippi. Average yield reductions on all treated acreage would be about 14 percent, while national production levels would not be significantly impacted. National soybean prices would not be affected. The net economic impact of cancellation would be a $558,000 loss, or about $14 per treated acre, borne entirely by producers.

Sugarbeet—Approximately 130,000 lb a.i. of chlorpyrifos 4E are applied to approximately 153,000 acres (12 percent) of sugarbeet in the United States. If chlorpyrifos 4E were canceled, total production would decrease slightly (less than 1 percent), leading to a 1 percent increase in price. Costs on acreage currently treated with chlorpyrifos 4E would decrease by $1. The net impact of cancellation would be a $1.9 million loss to the economy, consisting of a $6.5 million increase in producer surplus and an $8.4 million loss in consumer surplus.

Approximately 166,000 acres (13 percent) of sugarbeet are treated with chlorpyrifos 15G. This accounts for 232,000 lb a.i. applied annually. Sugarbeet root maggot is the primary target pest. If chlorpyrifos 15G were canceled, yield would decrease 5 percent on treated acreage since alternatives are not as efficacious. This would lead to a 1 percent increase in price. The use of alternative pest management measures would cause costs to increase slightly more than $1 per treated acre. The short-run net impact of cancellation would be a $10 million increase in producer revenues and a $13.4 million loss to consumers, resulting in a $3.4 million loss to the economy as a whole.

Sunflower (confection)—Chlorpyrifos 4E is applied to nearly 10,000 acres (3 percent) of confection sunflower production in the United States. This accounts for approximately 5,000 lb a.i. Cancellation of chlorpyrifos 4E would not change yield significantly, and treatment costs would increase nearly $3 per acre. The net economic impact of cancellation would be a slight loss of $27,000, borne entirely by producers.

Sunflower (oil)—In the United States, 30,000 lb a.i. of chlorpyrifos 4E is applied to 53,000 (3 percent) acres of oil sunflower production. Cancellation of chlorpyrifos 4E would have little effect on yield, and prices would remain unchanged. Cancellation of chlorpyrifos 4E would decrease treatment costs less than $1 per treated acre. The net economic impact of cancellation would be a $46,000 gain, realized entirely by producers.

Tobacco—Chlorpyrifos 4E is applied to approximately 144,000 acres (21 percent) of tobacco acreage in the United States, accounting for 362,000 lb a.i. Should chlorpyrifos 4E be canceled, tobacco yield changes would range from a 15 percent loss in Pennsylvania (3,900 acres) to a 5 percent increase in South Carolina (27,000 acres). Other States that would have production losses are Florida, Georgia, Maryland, and North Carolina. National production would increase slightly less than 1 percent on treated acreage, due to the superior performance of alternative wireworm control measures in South Carolina. Most alternatives, however, are Restricted Use pesticides. Higher insecticide expenditures would cause treatment costs to increase by more than $14 per treated acre. The market price of tobacco would not be significantly affected, as national production levels would remain fairly stable. The net economic impact of cancellation would be a $303,000 loss, borne entirely by producers.

Approximately 34,000 acres (5 percent) of tobacco production are treated with chlorpyrifos 15G. This accounts for 90,000 lb a.i. applied annually. Alternative pest management measures would result in yield losses of less than 1 percent on treated acreage. Costs to producers would increase by approximately $6 per treated acre as a result of use of higher priced alternatives. The market price for tobacco would not change significantly. The net economic impact of cancellation of chlorpyrifos 15G would be a loss of $637,000, borne entirely by producers.

Wheat—Although chlorpyrifos 4E is not currently labeled for use on wheat, EPA has granted Section 18 approval for its use in controlling Russian wheat aphid since 1988. Survey respondents indicate that chlorpyrifos 4E is applied to an average of approximately 2 million acres (3 percent) of wheat in the United States each year, accounting for 977,000 lb a.i. Although several alternatives are available, disulfoton, a Restricted Use pesticide, is the only consistently effective alternative in treating Russian wheat aphid. The disulfoton label prohibits grazing in treated fields. Average yield losses on treated acres due to the cancellation of chlorpyrifos 4E would be less than 2 percent, and total production would decline less than 1 percent. The change in the market price for wheat would be insignificant, while producer costs would decrease about $1 per treated acre. Cancellation of chlorpyrifos 4E would result in a net economic loss of $742,000, all borne by producers.

Seed Treatment

Chlorpyrifos is registered as a seed treatment on 13 crops: bean, clover, corn, cucumber, dill, mustard, okra, pea, pumpkin, rutabaga, soybean, sugarbeet, and turnip. Chlorpyrifos is applied as a seed treatment to more than 3.5 million acres of field corn (5 percent), 200,000 acres of sweet corn (25 percent), 1.5 million acres of bean (90 percent), and 213,000 acres (75 percent) of pea. There is no reported actual use for soybean, clover, and sugarbeet, while data for the remaining crops are not available. Insufficient data on the use levels and efficacy of alternatives prohibited the estimation of any economic impacts of cancellation.

Fruit Crops

Approximately 1.5 million lb a.i. of sprayable formulations of chlorpyrifos are applied to about 700,000 acres of fruit production. Cancellation of the registration of sprayable formulations of chlorpyrifos on all fruits would lead to economic losses exceeding $34 million.

In the United States, 21,000 acres of citrus production are treated with 49,000 lb a.i. of chlorpyrifos 15G. Insufficient data prohibited estimating the impact of cancellation on citrus.

For many fruits and nuts (discussed below), the economic impact of canceling a given insecticide is very often the cost associated with using an alternative. This is due to the fact that alternatives, in general, provide similar control of target pests. However, as with field corn, the loss of *all* insecticides could have substantial impacts on fruit and nut production, leading to potentially serious economic impacts (Bill Barnett, 1993, personal communication).

Apple—Chlorpyrifos 4E or 50WP is currently applied to approximately 188,000 acres (41 percent) of apple production, accounting for 374,000 lb a.i. applied annually. In the short-run, the use of alternative pest management measures would result in a slight decrease in yield, with production on treated acreage declining about 1.2 percent. Nationally, the decline in total production would be less than 1 percent—causing a 2 percent increase in price. The use of alternative pest management measures would increase costs on treated acreage by more than $3. The cancellation of chlorpyrifos 4E or 50WP would have a short-run net economic impact of a $9.0 million loss to the economy. This impact would consist of an increase in producer revenues of $25.5 million, and a $34.5 million decrease in consumer surplus.

In the long run, hastened pest resistance to remaining insecticides would have a much more severe economic impact. Assuming no new pesticides are developed, Kazmierczak et al. (1993)—utilizing a simulation model for mid-Atlantic States—estimate that removal of chlorpyrifos would result in $1.91 billion present-value loss of economic benefits projected over a 25 year period. This translates into an annual loss, amortized at 6 percent, of $150 million. The authors estimate that regional losses would be: $12.6 million over 5 years ($3 million per year), $833.6 million over 10 years ($113 million per year), and $1.77 billion over 15 years ($182 million per year).

The extended time period of analysis employed by the authors also allowed looking at long-term chemical use patterns if chlorpyrifos were canceled. After a slight short-term increase in per acre chemical use, the authors report an expected reduction in long-term chemical use, ranging from 14 percent to 37 percent. The authors argue that this reduction is a result of pest susceptibility depletion becoming "a serious enough threat to require reduced insecticide use in an attempt to forestall the emergence of resistance" (Kazmierczak et al., 1993).

The severity of the above long-term economic impact might be somewhat lessened by the development of new nonchemical pest control techniques. For instance, many apple growers in Washington are moving to "soft-control" measures such as mating disruption. As a result, use of chlorpyrifos and other chemical insecticides is expected to decline (Elizabeth Beers, 1993, personal communication).

Citrus—Chlorpyrifos 4E is applied to approximately 336,000 acres (39 percent) of citrus in the United States, accounting for 955,000 lb a.i. Most alternative insecticides are Restricted Use. In Texas and California, chlorpyrifos 4E is the most effective control for red scale. Methidathion, petroleum oil, and carbaryl are the primary alternatives to chlorpyrifos 4E. Methidathion and oil are equally efficacious, and carbaryl is less effective. Without chlorpyrifos 4E, decreased fruit quality due to scale damage on acreage treated with less effective control measures would require affected growers in California and Texas to downgrade approximately 1 percent of their product to processing or grade 2, rather than sell the fruit as grade 1. Process grade sells for approximately $4 less per box than grade 1, and grade 2 sells for about $1 less per box. Downgrading 1 percent of production on affected acreage to grade 2 would result in a revenue loss for farmers of $350,000, while downgrading 1 percent of production on affected acreage to process grade would decrease revenues by more than $1.4 million.

Perhaps the most critical economic aspect of chlorpyrifos 4E is its role in IPM. Carbaryl and methidathion are more toxic to natural enemies than is chlorpyrifos 4E (Joseph Morse, 1993, personal communication). Thus, loss of chlorpyrifos could lead to an increase in the number of pesticide applications per year. Costs of applying a pesticide to citrus in California are estimated to range between $60 and $80 per acre.

In the short run, cancellation of chlorpyrifos 4E would have minimal impact on product price, and per acre treatment costs would increase by more than $14 per treated acre, for a total of $4.8 million. When factoring in quality losses, the short-run net economic impact as a result of cancellation would be a loss ranging between $5.2 million and $6.3 million.

Nearly 49,000 lb a.i. of chlorpyrifos 15G are applied to approximately 21,000 acres (2.5 percent) of U.S. citrus. Chlorpyrifos 15G is used exclusively to control ant problems. In the event of cancellation of the granular formulation, alternative ant control measures are available in most citrus-producing States, but chlorpyrifos 4E is the only insecticide rated as effective as the granular formulation. Diazinon and baits are other alternatives. Uncontrolled ants can enhance scale populations, which secrete honeydew that ants consume. Increased scale pressure could cause some growers to make additional insecticide applications. The costs of an additional application range from $20 to $80 per acre. Furthermore, fire ants can kill or damage young citrus trees if uncontrolled. Data necessary to determine the economic impacts of the ant situation are not available. As a result, the economic impact of canceling chlorpyrifos 15G was not calculated.

Canceling both formulations of chlorpyrifos would limit growers' ability to control fire ants on citrus. Due to lack of data on infested acreage and effects on marketable production, the monetary impact of uncontrolled fire ants could not be estimated.

Cranberry—Approximately 10,000 acres (38 percent) of U.S. cranberries are treated with chlorpyrifos 4E. This accounts for more than 21,000 lb a.i. Cancellation of chlorpyrifos 4E would reduce total production nearly 6 percent. The use of alternative pest management measures would increase per acre treatment costs by more than $5. Due to the absence of price elasticity data, the change in price and impacts on consumers and producers could not be calculated. The effect of cancellation would be a net loss of more than $9.5 million to the economy.

Grape—Chlorpyrifos 4E is applied to approximately 14,000 acres (1.9 percent) of grape acreage in the United States, accounting for 20,000 lb a.i. per year. The primary pests on treated acreage are grape root borer and climbing cutworm. If the registration of chlorpyrifos 4E were canceled, no effective substitute would be available to control these pests. As a result, costs per treated acre will decrease by $11, while yield on treated acreage would be reduced by 4 percent or more. The largest production impacts will be in the Southeast and Michigan. Since chlorpyrifos is used on only a small percentage of total acreage, overall production impacts would be insignificant. As a result, grape prices are not expected to change. The net effect of cancellation would be a $182,000 loss to the economy, borne entirely by producers.

Nectarine—Nearly 5,000 acres (20 percent) of nectarine production in the United States are treated with chlorpyrifos 4E, accounting for 10,000 lb a.i. applied annually. All reported treated acreage is in California. In the event of cancellation, nectarine growers would employ alternative pest management measures that offer similar performance. Nectarine prices would not be affected by cancellation of chlorpyrifos 4E, while costs per treated acre would increase by $44, due to the higher cost of alternative treatments. The overall net economic impact would be a $214,000 loss to the economy, borne entirely by growers.

Peach—Approximately 72,000 lb a.i. of chlorpyrifos 4E are applied to 77,000 acres of peach production in the United States. The acreage total reflects, in part, treatments of the same acreage at different times of the season. For example, some acreage is treated at both dormant and in-season stages of production. In the short run, cancellation would have little effect on output; therefore, price would remain unchanged. The switch to alternative pest management measures would increase costs on acreage currently treated with chlorpyrifos 4E by nearly $12 per acre. This would result in a $909,000 increase in pesticide expenditures.

Survey returns indicate that 53,680 acres are treated for peachtree borer. One longer term implication of the cancellation of chlorpyrifos is that borer damage to young peach trees may force growers to replace affected trees. Extension experts indicate that tree loss could be 25 percent on young blocks that go untreated (Clyde Gorsuch, 1993, personal communication). Endosulfan, though less efficacious, would mitigate these losses.

An enterprise orchard budget for peach orchards developed by Clemson University Cooperative Extension Service was used to determine replacement costs and production impacts. The results assume 15 years of full production, with salable fruit produced 4 years after planting. Thus, replacement is assumed to occur every 18 years. Alternatives to chlorpyrifos were assumed to increase tree loss by 5 percent. An acre of peach production was valued at $3,700. Variable costs for first-year peach trees are $1,168 per acre. The total economic loss was determined by summing replacement costs (RC), losses in revenue (RL), and changes in chemical costs (dCC).

RC = [(53,680 acres/18 years) x $1,168/acre x 5%] = $174,162/year
RL = [(53,680 acres/18 years) x $3,700/acre x 5%] = $551,711/year
dCC = $909,257

Under this scenario, the net impact of cancellation would be a $1.6 loss to the economy. The distribution of this impact amongst producers and consumers was not estimated.

Pear—Chlorpyrifos 4E is applied to approximately 15,000 acres (21 percent) of pear production in the United States. This accounts for more than 15,000 lb a.i. The cancellation of chlorpyrifos 4E would have little effect on output because similarly efficacious alternatives are available; therefore, prices would remain unchanged. The switch to alternatives would raise production costs on treated acreage by $18 per acre. The short-run economic impact of cancellation would be a $273,000 loss to producers and the economy as a whole.

Plum/Prune—Chlorpyrifos 4E is applied to 10,000 acres (8 percent) of plum/prune in the United States, primarily to control San Jose scale. All reported use is dormant application. This accounts for nearly 20,000 lb a.i. applied annually. In the event the registration of chlorpyrifos 4E is canceled, plum/prune yields would decrease slightly on treated acreage. Nationally, production would decrease less than 1 percent, and price would not change. Scale damage could make some fruit unmarketable. The switch to alternative pest management measures would cause per acre treatment costs to increase nearly $10. Should chlorpyrifos 4E be canceled, the economic impact would be a $429,000 loss to the economy, all borne by producers.

Strawberry—Chlorpyrifos 4E is applied to approximately 4,800 acres (10 percent) of strawberry production in the United States, accounting for 7,000 lb a.i. applied annually. Cancellation would lead to a 30 percent decline in production on treated acreage, and a 1 percent decline in total production. Application of substitute insecticides would increase costs on acreage treated with chlorpyrifos 4E by $2 per acre. The price of strawberries would increase nearly 3 percent in the short run. The net economic impact of cancellation would be a $7.1 million loss to the economy, with producer revenues increasing $12.1 million and consumer surplus decreasing by $19.2 million.

Nut Crops

About 900,000 lb a.i. of sprayable formulations of chlorpyrifos are applied to approximately 440,000 acres of nut production in the United States. Cancellation of the registration of chlorpyrifos on all nut crops would result in a net economic loss of $4 million. Though alternatives generally provide similar protection, resistance is a potential problem, especially in walnut.

Almond—In the United States, 5 percent of in-season (20,435 acres) and 5 percent of dormant (20,435 acres) almond production is treated with chlorpyrifos 4E or 50WP, accounting for 82,000 lb a.i. Alternative pest management techniques provide, on the whole, equally efficacious crop protection, though some alternatives provide superior control and others are inferior to chlorpyrifos (Bill Barnett, 1993, personal communication). Subsequently, production would remain unchanged, and cancellation would not affect short-run almond prices. The use of alternative insecticides brought about by cancellation of chlorpyrifos would increase treatment costs more than $9 per acre due to higher insecticide expenditures and/or additional numbers of treatments. The net economic effect of cancellation of chlorpyrifos 4E would be a $381,000 loss in the short run, which would be incurred by producers.

Filbert—In the United States, more than 19,000 acres (73 percent) of filbert production are treated with 39,000 lb a.i. of chlorpyrifos 50WP. Chlorpyrifos 50WP effectively controls leafrollers and aphids. This chemical's strong showing in the marketplace is primarily due to its fuming action that allows more flexibility in timing of application (Jeff Olsen, 1993, personal communication). In general, alternatives are equally efficacious, with the exception of carbaryl and endosulfan, which are considered less effective against aphids. In the short run, the use of alternative insecticides would lead to yield reductions of less than 1 percent on treated acreage, while costs per treated acre would decrease more than $4. The decline in national production would be slight. The net economic impact of canceling chlorpyrifos 50WP would be a gain of more than $20,000, about $1 per treated acre, accrued entirely by producers.

Pecan—Chlorpyrifos 4E or 50WP is applied to approximately 272,000 acres of pecan production in the United States. This accounts for 360,000 lb a.i. If chlorpyrifos 4E and 50WP were canceled, alternative pest management measures would provide similarly effective short-run protection. The use of alternatives would cause treatment costs to increase less than $1 per treated acre. The economic impact of cancellation would be a $57,000 loss to the economy. All losses would be incurred by growers through higher pesticide expenditures.

Chlorpyrifos 4E is the only labeled insecticide effective in controlling fire ants (39,000 acres). Fire ants, while having no direct impact on yield, can be a problematic pest. This is due to the fact that uncontrolled fire ants can compound aphid problems by killing other insects that would normally feed on aphids. Aphids are a secondary pest in pecan, and can have adverse effects on production, especially considering a demonstrated increased resistance of yellow aphids to existing insecticides (H.C. Ellis, 1993, personal communication). To control increased aphid infestation, growers would have to apply additional insecticides. The economic impact discussed above includes a cost estimate of these additional applications.

Walnut—Chlorpyrifos 4E or 50WP is applied to 105,000 acres (60 percent) of walnut production in the United States. This accounts for 420,000 lb a.i. applied annually. Due to the superior performance of alternative pest management measures in controlling codling moth (a pest affecting nut quality), the cancellation of chlorpyrifos 4E and 50WP will not result in reduced production. Thus, walnut prices would remain unchanged. However, the use of alternative pest management measures will increase per acre treatment cost by nearly $34, as alternative treatments are more expensive. Cancellation of the sprayable formulations of chlorpyrifos would cause a producer loss of $3.6 million.

Vegetables

In the United States, 229,000 acres of vegetable production are treated with approximately 460,000 lb a.i. of sprayable formulations of chlorpyrifos. Cancellation of the registration of this formulation for use on vegetables would result in a net economic loss of $11 million to the economy.

Approximately 200,000 lb a.i. of chlorpyrifos 15G are applied to 130,000 acres of vegetable production. Cancellation of chlorpyrifos 15G for use on vegetables would result in a net economic loss of $7 million.

Asparagus—Chlorpyrifos 4E is applied to 22,000 acres (21 percent) of asparagus in the United States, accounting for an annual usage of 42,000 lb a.i. If chlorpyrifos 4E were canceled, required use of alternative pest management measures would cause yields per treated acre to decrease by 2 percent, while total production would decrease less than 1 percent. The use of alternative pest management measures would reduce costs by $10 on acreage currently treated with chlorpyrifos 4E. Because elasticities were not available, changes in price, consumer, and producer revenue were not computed. The net economic impact of cancellation would be a $729,000 loss to the economy.

Broccoli—Approximately 16,000 acres (14 percent) of broccoli production in the United States are treated with chlorpyrifos 4E or 50WP. This accounts for more than 28,000 lb a.i. applied annually. Alternatives to chlorpyrifos 4E are generally less effective, with yield losses on treated acres ranging from 0 percent to 10 percent. However, alternatives to chlorpyrifos 50WP in California, which accounts for 65 percent of acreage treated with sprayable chlorpyrifos, are slightly more effective (1 percent yield increase). As a result, broccoli production would increase slightly, and the price of this crop would not be affected. The use of alternative measures would cause costs to decrease nearly $8 per treated acre. The net economic impact of cancellation would be a gain of $220,000 to the economy. The entire loss would be incurred by producers. Chlorpyrifos 15G is applied to approximately 24,000 acres (20 percent) of broccoli production, accounting for 33,000 lb a.i. applied annually. Most reported use is in California (21,000 acres). If chlorpyrifos 15G were canceled, per acre costs would increase more than $10 on treated acreage, for a total of $245,000. The use of available alternative pest control measures would lead to yield losses averaging 1 percent on treated acreage, but would range between 5 and 15 percent on treated acreage in Florida and Maine. Impacts on national production levels would be minimal, and price would not be affected. The decline in production implies that a net economic impact of cancellation would be an $858,000 loss to the economy. Due to the absence of a price elasticity for broccoli, it is not possible to determine the distribution of the economic impact amongst producers and consumers.

Brussels sprout—Chlorpyrifos 4E or 50WP is applied to 100 percent of reported brussels sprout production, which occurs primarily in California. This accounts for approximately 15,000 lb a.i. applied annually. One hundred percent of the acreage in California is treated for aphids, and 40 percent is treated for cabbage maggot. If the sprayable formulations of chlorpyrifos were canceled, alternative pest management measures would be available, with fewer treatments allowing production costs to decrease nearly $23 per treated acre, for a total of $100,000. These alternatives, however, are less effective, and production would decrease more than 5 percent. The net economic impact of cancellation would be a $805,000 loss to the economy. The distribution of this loss amongst producers and consumers was not calculated due to the absence of elasticity data.

Chlorpyrifos 15G is applied to slightly more than 3,000 acres of U.S. brussels sprout production, accounting for 8,000 lb a.i. All reported use is in California, and most acreage is treated with chlorpyrifos 15G as well as several other insecticides. Should chlorpyrifos 15G be canceled, the availability of alternative pest control measures would cause per acre treatment costs to decrease by $17, due to lower insecticide expenditures. Total production costs would decrease $52,000. Cancellation would lead to yield losses between 5 percent and 15 percent on treated acreage. The net economic impact of cancellation would be a $1.6 million loss to the economy, primarily attributed to reduced output. Due to the absence of a price elasticity, the distribution of this impact amongst producers and consumers was not estimated.

Cauliflower—Chlorpyrifos 4E or 50WP is applied to approximately 24,000 acres (36 percent) of cauliflower production in the United States, accounting for 37,000 lb a.i. Chlorpyrifos 4E provides superior control for root maggots; yield losses with alternatives are estimated at 0 to 10 percent. Alternative insecticides for aphids provide superior control, with yields on acres treated with dimethoate and disulfoton 5 percent higher than those treated with chlorpyrifos 50WP. Nationally, should chlorpyrifos 4E and 50WP be canceled, average yield per treated acre would increase about 1 percent. Average per acre insecticide expenditures for alternatives are similar, leading to a cost decrease of less than $1 per treated acre. The price of cauliflower would not change significantly. The net economic impact of cancellation would be a gain of $494,000 in the short run.

Chlorpyrifos 15G is applied to approximately 32,000 acres (47 percent) of cauliflower production, accounting for 49,000 lb a.i. applied annually. Most of the reported treated acreage is in California. If chlorpyrifos 15G were canceled, per acre costs would decrease $1 on treated acreage. Chlorpyrifos 15G provides superior control for root and cabbage maggots as compared to diazinon. As a result, total production would decrease slightly less than 1 percent if chlorpyrifos 15G were canceled, and the short-run price of cauliflower would not be affected. The net economic impact of canceling chlorpyrifos 15G would be a $738,000 loss, all borne by producers.

Cancellation of both formulations of chlorpyrifos would have a significant economic impact on cauliflower production, due primarily to yield reductions resulting from root maggots. Currently, 58 percent of reported acreage is treated with one or both formulations. Yield on treated acreage would decline (on the average) more than 9 percent, while national output would be reduced by more than 5 percent. Without chlorpyrifos, production costs would decrease $10 per treated acre. Due to sharp reductions in output, the net economic impact of cancellation would be an $11.4 million loss to the economy. Since a price elasticity was not available, it is not possible to estimate the distribution of the impact amongst consumers and producers.

Chinese cabbage—Approximately 7,500 lb a.i. of chlorpyrifos 4E or 50WP are applied to 1,300 acres (15 percent) of Chinese cabbage production. In the event the registration of the sprayable formulations of chlorpyrifos were canceled, the use of alternative pest management strategies would cause production costs to decrease more than $15 per treated acre, for a total of $20,000. This is primarily because fewer applications of the alternatives to chlorpyrifos 50WP would be required in Florida (1,200 acres). The generally superior performance of chlorpyrifos in controlling the worm complex in Florida implies that cancellation would lead to production losses from 0 to 10 percent on treated acreage. The net economic impact of cancellation would be an $11,000 gain to the economy. Because elasticity data are unavailable, it is not possible to estimate the distribution of this impact amongst producers and consumers.

Chlorpyrifos 15G is applied to nearly 400 acres (4 percent) of Chinese cabbage production, accounting for 500 lb a.i. If chlorpyrifos 15G were canceled, the use of alternative insecticides would increase per acre costs more than $6 on treated acreage, for a total of $2,500. Yield losses attributed to cancellation would range from 5 percent to 15 percent on treated acreage. The net economic impact of cancellation would be a $5,000 loss to the economy. Due to the absence of a price elasticity, the distribution of the economic impact of cancellation was not calculated.

Head cabbage—Approximately 29,000 acres (40 percent) of U.S. head cabbage production are treated with 67,000 lb a.i. of chlorpyrifos 4E or 50WP. If the registrations of sprayable formulations of chlorpyrifos were canceled, yield changes attributed to alternative pest management techniques would range from -10 percent to +5 percent on treated acreage. Neither national production nor price would change significantly. However, production costs would increase less than $1 per treated acre when alternative pest management strategies are used. The total increase in production costs would be $7,000. The net economic impact of cancellation would be a $1.5 million loss to the economy, borne entirely by producers.

Chlorpyrifos 15G is applied to more than 6,700 acres (9 percent) of head cabbage production, accounting for 7,400 lb a.i. applied annually. If chlorpyrifos 15G were canceled, the use of alternative pesticides would cause production costs to increase more than $7 on acreage currently treated with chlorpyrifos, for a total of $46,000. The use of alternative pest control measures would lead to production losses of about 4 percent on treated acreage. Production losses would result in a slight price increase (less than 1 percent). The net economic impact of cancellation would be a $723,000 loss to the economy, with producers experiencing a $301,000 decline in net revenue, while consumer surplus would decrease $422,000.

Collard—Chlorpyrifos 4E or 50WP is applied to approximately 300 acres of collard production, accounting for 490 lb a.i. If chlorpyrifos 4E and 50WP were canceled, the use of alternative pest management techniques would increase per acre costs nearly $9, while production losses would range from 0 to 5 percent on treated acreage. Total production would decline less than 1 percent. The net economic impact of cancellation would be a $2,500 loss to the economy, borne entirely by producers.

Approximately 1,300 acres of collard production are treated with chlorpyrifos 15G, accounting for nearly 1,000 lb a.i. The majority of use is in Florida (1,200 acres) for root maggots and soil insects. The survey indicates that no alternative is available to treat root maggots. If chlorpyrifos 15G were canceled, Florida test plots indicate that production losses would range from 5 to 50 percent. Cancellation would result in a $4 increase in per acre treatment costs. The combination of reduced output and higher per acre pesticide expenditures results in a net economic loss of $166,000 due to cancellation. Since no price elasticity was available, the distribution of the impact amongst producers and consumers was not estimated.

Kale—Chlorpyrifos 4E or 50WP is applied to approximately 500 acres (8 percent) of kale production, accounting for 1,000 lb a.i. If chlorpyrifos 4E and 50WP were canceled, the use of alternative pest management techniques would decrease per acre costs less than $4. For most pests, the use of alternative pest control measures would cause yields to decrease between 0 and 10 percent on treated acreage. The impact of cancellation on national production would be minimal. The net economic impact of cancellation would be a loss of $38,000. All losses would be incurred by the growers.

Approximately 400 acres (6 percent) of kale production are treated with chlorpyrifos 15G, accounting for less than 500 lb a.i. If chlorpyrifos 15G were canceled, alternative pest management strategies would cause yields to decrease between 0 and 15 percent on treated acreage. Using alternatives would cause costs per treated acre to increase nearly $12, for a total increase in production costs of less than $5,000. The impact on national production would be insignificant. The net economic impact of cancellation would be a $38,000 loss, borne entirely by producers.

Kohlrabi—Less than 50 acres of kohlrabi production are treated with chlorpyrifos 50WP, accounting for less than 75 lb a.i. All reported use is in Arizona. If chlorpyrifos 50WP were canceled, the use of alternative pest control measures would cause per acre treatment costs to decrease by $4, totalling less than $200, while production would decline between 5 percent and 10 percent on treated acreage. The effect of cancellation on the national economy would be a loss of less than $9,000.

Mint—Approximately 36,000 acres (34 percent) of mint production are treated with chlorpyrifos 4E, accounting for 68,000 lb a.i. In Idaho, Oregon, and Washington, chlorpyrifos 4E is used primarily to control the mint root borer. No effective substitute is currently registered for this insect. Since no alternative insecticides can be applied, cancellation of chlorpyrifos 4E would reduce production costs $17 per acre. Production losses on infested acreage could reach 25 percent in Idaho and Oregon and 10 percent in Washington the first year chlorpyrifos was not available. As a result, national production would be reduced more than 6 percent. Because price elasticities were not available, price, consumer, and producer revenue impacts were not computed. The net economic impact in the event of cancellation would be a loss of approximately $5.6 million in the short run.

Onion—Nearly 16,000 acres (12 percent) of onion production are treated with chlorpyrifos 4E, accounting for more than 18,000 lb a.i. Most treated acreage is in New York (10,500 acres) and Georgia (2,900 acres). If the registration of chlorpyrifos 4E were canceled, the use of alternative pest management measures would lead to yield losses of 1 percent on treated acreage. Alternatives to chlorpyrifos 4E in New York would lead to yield losses ranging from 0 percent (chlorpyrifos 15G) to 70 percent (rotation). Impacts of cancellation on total production would be small. As a result, the price of onions would be unchanged. The use of alternatives would increase costs on treated acres by approximately $2. The net economic impact of cancellation would be a $198,000 loss to the economy, borne entirely by producers.

Chlorpyrifos 15G is applied to more than 12,500 acres (9 percent) of onion production, primarily to control onion maggot. This accounts for 28,000 lb a.i. Production impacts of cancellation would be most severe in New York (1,300 acres), Oregon (2,200 acres) and Washington (1,100 acres), where yield losses would range from 0 to 70 percent on treated acreage. Cancellation of chlorpyrifos 15G would decrease average yields on treated acreage by 11 percent, while the change in total output would be less than 1 percent. As a result, onion prices would increase 1 percent. Alternative treatments would reduce production costs by $5 per treated acre. The net economic effect of cancellation would be a $2.5 million increase in producer revenues, a $3.3 million loss to consumers, and a $765,000 loss to the economy.

The increase in producer revenues is attributed mainly to the fact that growers not currently using chlorpyrifos 15G would realize the price increase attributed to lower supplies without having their own production reduced. The economic impact on those growers using chlorpyrifos 15G would be a decline in revenue of nearly $860,000. This decline would be partially offset by a $60,000 reduction in production costs due to the use of alternatives.

Should both formulations of chlorpyrifos be canceled, no alternative treatment for seedcorn maggot would be available in Georgia, and yield losses in this State would range from 20 to 40 percent. New York, Washington, and Michigan also rely heavily on both formulations for onion maggot. If both the sprayable and granular formulations of chlorpyrifos were canceled, national production would decline nearly 2 percent, causing a 7 percent increase in price. Per acre treatment costs would decrease less than $3. The net economic impact of cancellation of both formulations would be a $10.3 million loss, with producer surplus increasing $29 million and consumer surplus decreasing $39.3 million. As above, increased revenues would accrue primarily to those growers not currently using chlorpyrifos.

Radish—Chlorpyrifos 4E is applied to more than 1,800 acres of radish production. This accounts for 3,000 lb a.i. applied annually. If chlorpyrifos 4E were canceled, the use of alternative pest management measures would increase per acre treatment costs by more than $4, for a total increase of $8,300. Chlorpyrifos 15G is equally efficacious as an alternative, but its use would require equipment modifications. The use of other labeled insecticides would lead to production losses between 10 and 50 percent on treated acreage. The net economic effect of cancellation would be a loss of nearly $575,000. Due to the absence of a price elasticity, the impacts on producer and consumer surplus were not estimated.

Approximately 8,500 acres of U.S. radish production are treated with chlorpyrifos 15G, accounting for more than 16,000 lb a.i. If chlorpyrifos 15G were canceled, the use of alternative pest management measures would cause per acre treatment costs to decline less than $1. Without chlorpyrifos 15G, production losses would average about 2 percent on treated acreage. The net economic impact of cancellation would be a $1 million loss to the economy, due primarily to reduced output. Due to the absence of a price elasticity, consumer and producer effects were not estimated.

In Washington, chlorpyrifos is applied to nearly all radish acreage. Canceling both formulations could result in yield losses between 40 and 50 percent in the State, as labeled alternatives are less efficacious. The net economic impact of cancellation of both formulations would be a loss of nearly $3.1 million. Losses of such magnitude would force many growers out of radish production. As a result, production in other areas and/or imports could increase. The effect on growers forced out of the radish market would be the difference between the profitability of radish production and the alternative crop.

Rutabaga—Approximately 200 acres of rutabaga production are treated with chlorpyrifos 4E. This accounts for 400 lb a.i. If chlorpyrifos 4E were canceled, chlorpyrifos 15G would be the only labeled alternative. Because chlorpyrifos 15G is equally efficacious, cancellation of the sprayable formulations of chlorpyrifos will leave yield and price unchanged, while costs per treated acre would increase $3. The net economic loss of cancellation would be less than $1,000.

Chlorpyrifos 15G is applied to approximately 400 acres of rutabaga production, accounting for 995 lb a.i. In the event of cancellation, chlorpyrifos 4E is the only labeled alternative. There would be no yield losses associated with the use of the sprayable formulations of the alternative. As a result, price would remain unchanged, while production costs would decrease by $3 on treated acreage. The net economic impact of cancellation would be a $1,400 gain.

Cancellation of either the sprayable or the granular formulations would require some farmers to make equipment modifications. If both formulations were canceled, production losses would exceed 58 percent because no labeled alternatives are available. This could force many growers out of rutabaga production and into alternative crops. The net economic impact of canceling both formulations would be a $3.4 million loss to the economy. Due to the absence of a price elasticity, it is not possible to estimate the distribution of this impact amongst producers and consumers.

Sweet corn—Approximately 42,400 acres (6 percent) of sweet corn production in the United States are treated with chlorpyrifos 4E. This accounts for more than 107,000 lb a.i. If chlorpyrifos 4E were canceled, the use of alternative pest management measures would lead to insignificant declines in total production. Subsequently, price would remain unchanged. The use of alternatives would increase costs by more than $4 per acre on acreage currently treated with chlorpyrifos 4E, due in part to an increased number of treatments in New York and Wisconsin. The net economic impact of cancellation of chlorpyrifos 4E would be a $240,000 loss to the economy, all borne by producers.

Chlorpyrifos 15G is applied to approximately 24,900 acres (4 percent) of sweet corn acreage, averaging 32,000 lb a.i. per year. If chlorpyrifos 15G were canceled, the use of alternative insecticides would lead to insignificant declines in production, and price would remain unchanged. Production costs would increase about $1 per treated acre. The economic impact caused by cancellation would be a net loss of $42,000. Losses would only affect producers.

Sweetpotato—Approximately 32,000 acres (36 percent) of U.S. sweetpotato production are treated with chlorpyrifos 4E, accounting for 66,000 lb a.i. Of all the labeled insecticides, chlorpyrifos is deemed most efficacious against target pests. If chlorpyrifos 4E is canceled, yields per treated acre would decrease 2 percent, while total production would decrease 1 percent. The use of alternative pest management measures would increase costs on treated acreage by more than $6 per acre. Because price elasticities were not available, price, consumer, and producer revenue impacts were not estimated. The net economic impact of cancellation would be a loss of $1.6 million.

Chlorpyrifos 15G is applied to more than 10,000 acres (12 percent) of U.S. sweetpotato acreage. This accounts for 22,000 lb a.i. Cancellation of chlorpyrifos 15G would decrease sweetpotato yields on treated acreage 3 percent, while total output would decline less than 1 percent. Price changes were not computed, since price elasticities were not available. Cancellation would cause production costs to increase nearly $6 per treated acre. The net economic effect of cancellation would be a $642,000 loss.

Turnip—Approximately 600 acres of turnip production are treated with chlorpyrifos 4E, accounting for 700 lb a.i. Should chlorpyrifos 4E be canceled, chlorpyrifos 15G would be the only effective substitute. This substitution would create a need for farmers to make equipment adjustments. If chlorpyrifos 4E were canceled, output and price would be unchanged, while costs per treated acre would increase more than $2. The net economic impact of cancellation would be a $1,400 loss to the economy, borne entirely by producers.

Chlorpyrifos 15G is applied to approximately 600 acres of turnip production, accounting for 1,000 lb a.i. If chlorpyrifos 15G were canceled, chlorpyrifos 4E would be the only alternative utilized. Cancellation would leave output and prices unchanged, while production costs would decrease by $5 per acre on treated acreage. However, farmers would be required to make equipment changes. The net economic impact of cancellation would be a $3,400 gain.

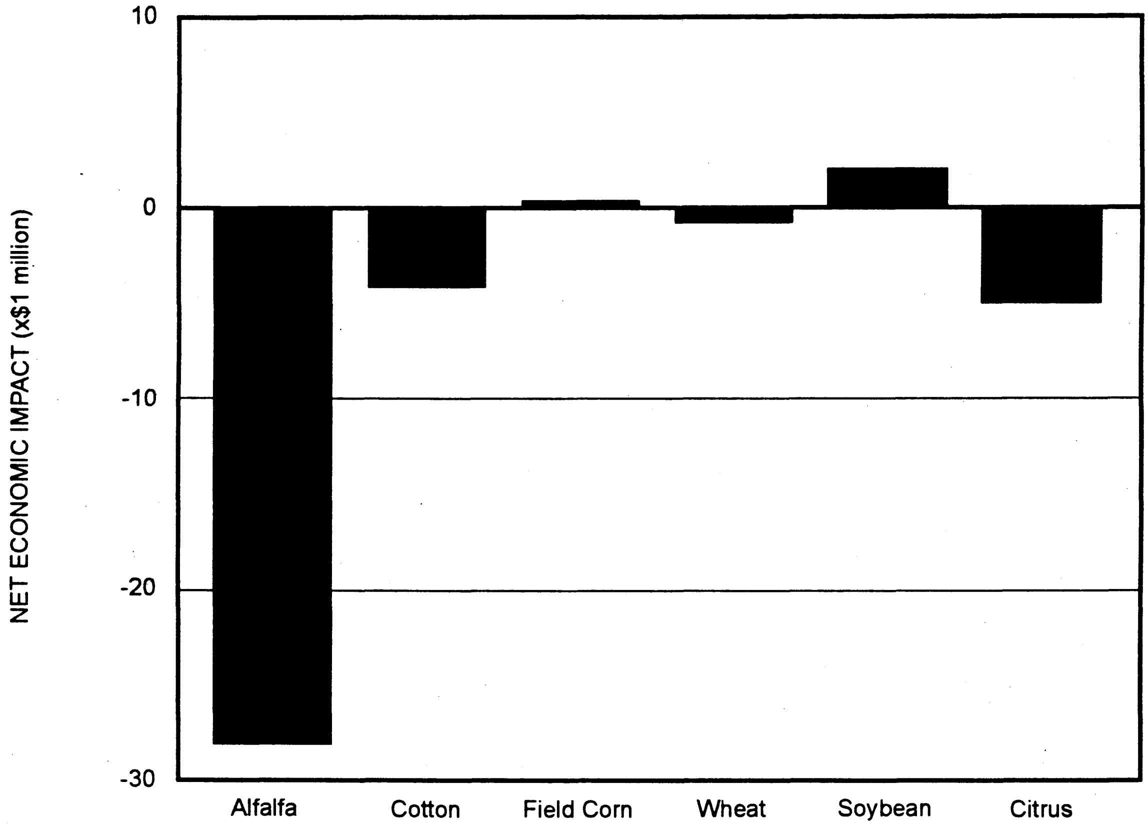
Either the granular or sprayable formulations of chlorpyrifos are used on all turnip acreage reported in the survey (1,219 acres) to control root maggot. Should both formulations be canceled, experts suggest that yield losses could range from 10 percent to 100 percent, depending on the severity of infestation (Ed Grafius, 1993, personal communication). These losses would be attributed to the fact that there are no labeled alternatives. Many growers would be forced to replant—although this would not rid the field of the pest. Not treating acreage would reduce production costs by about $14 per acre. Assuming a 50 percent yield loss on all treated acreage, and also assuming farmers were to continue to grow turnips, the net economic impact would be a loss of more than $1 million.

A more likely effect of cancellation would be increased imports and/or production elsewhere, with farmers affected by cancellation switching to an alternative crop. The net economic impact on these growers would be the difference in profitability between turnips and the alternative crops.

Summary

Chlorpyrifos 4E and 50WP—In the United States, approximately 11.7 million lb a.i. of sprayable formulations of chlorpyrifos are applied to 12.6 million acres of crop production. The estimated short-term economic impact (sum of producer and consumer effects) that would result from the cancellation of the sprayable formulations of chlorpyrifos would be a loss of $86 million per year. Figure 3 represents the net economic impact of cancellation on the major use crops (i.e., those being treated with the highest total lb a.i.). Of the major use crops, losses would be greatest for producers and consumers of alfalfa ($28.9 million), citrus ($5.8 million) and cotton ($4.6 million). The net impact on corn and soybean would be gains

Figure 3. Economic Impact of Canceling Emulsifiable Chlorpyrifos
[Major Use Crops]

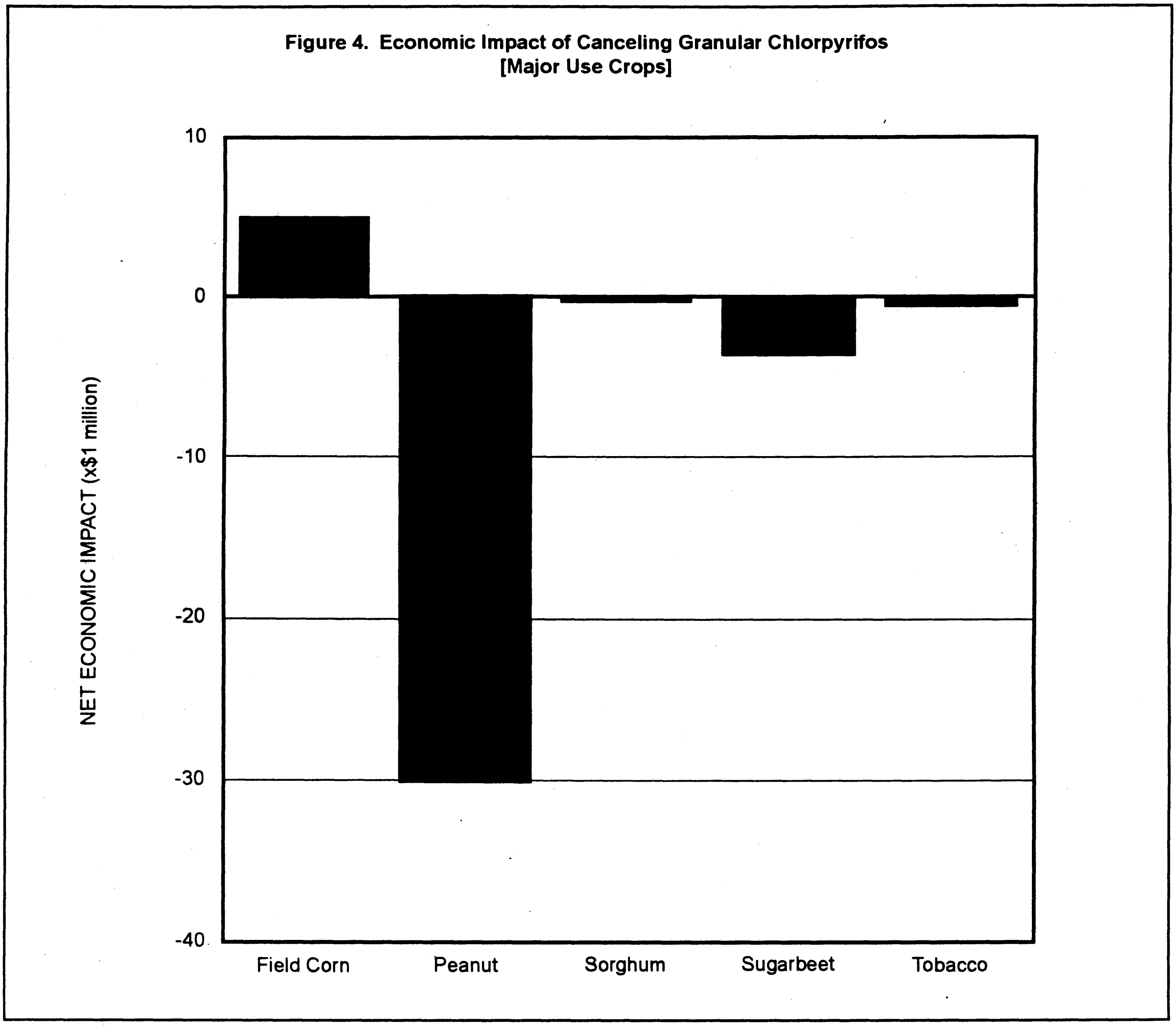


of $300,000 and $2 million, respectively. Wheat loss would be $750,000.

Of all crops treated with sprayable formulations of chlorpyrifos, the net economic loss due to cancellation would be greatest on alfalfa, cranberry ($9.5 million), apple ($9.1 million) and strawberry ($7.1 million). Production impacts would be most severe for growers of cranberry, grass seed, brussels sprout, and mint, for which alternatives are not nearly as effective as chlorpyrifos. The production, cost, and price impacts of cancellation on other crops would not be as substantial.

Chlorpyrifos 15G—Approximately 10 million lb a.i. of chlorpyrifos 15G are applied to 8.1 million acres of U.S. crop production. If the registration of chlorpyrifos 15G were canceled, net economic impacts would amount to a $37 million loss to the economy. Figure 4 represents the net economic impact of the cancellation of chlorpyrifos 15G on the major use crops. The effects are most notable on peanut ($30.3 million loss) and field corn. Consumers most affected by the proposed cancellation are those purchasing peanut. Prices would increase more than 4 percent, and the net economic loss for peanut consumers would be $47.6 million. The net economic impact on field corn, on the other hand, would be a $4.8 million gain, due primarily to superior yield performance of alternatives in Nebraska.

There are several plausible reasons why field corn producers would use chlorpyrifos, even through cancellation would cause a net economic gain. First, the slight decrease in per acre costs is insignificant. Second, chlorpyrifos is a broad-spectrum insecticide that is effective in controlling many different insect species. Thus, single applications may serve to control two or more pest populations. Finally, chlorpyrifos is a General Use rather than a Restricted Use pesticide, so that applicators need not be certified. As a result, farmers may perceive chlorpyrifos to be safer than some of the alternatives, resulting in an intangible benefit not quantified in this analysis. A study by DowElanco, not validated by NAPIAP, indicated that such attributes as safety to humans, broad-spectrum control, and compatibility with sulfonyl urea herbicides could each be worth more than $1 per acre to corn growers (Bacon, 1993). If this is the case, then the value of these attributes would justify the use of chlorpyrifos by corn growers.



Canceling all formulations of chlorpyrifos would lead to short-term economic losses of about $150 million. In addition to the crops mentioned above, cauliflower ($11.4 million loss), onion ($10.3 million loss), radish ($3.1 million loss), rutabaga ($3.3 million loss), and turnip ($1 million loss) would be heavily impacted by cancellation of both formulations. Although farmers could substitute one formulation for the other, few effective alternatives to chlorpyrifos are available for these crops. As a result, many growers of these crops would grow alternative crops or be forced out of business.

Chlorpyrifos Use on Alfalfa

Wayne C. Bailey

INTRODUCTION

Alfalfa, *Medicago sativa* L., is a perennial, high-quality forage that originated in Asia and was first introduced into the United States in the early 1700's, then reintroduced in the mid-1850's after being carried to many parts of the world for livestock feed (Barnes et al., 1988). More than 590 different insect species have been collected from this crop in the Eastern United States (Pimental and Wheeler, 1973), and more than 1,000 species of arthropods have been collected from irrigated alfalfa in California (Anonymous, 1985). Eighty percent or more of these arthropods do not damage the crop. Many of these arthropods are beneficial to alfalfa because they are predaceous, and therefore, their presence increases the natural control of pest species; others are beneficial in that they are important crop pollinators.

Insecticides applied as foliar sprays are used to control arthropod pests on seedling and established alfalfa plants. These insecticides provide protection against most pest species. These pests restrict alfalfa production by reducing forage quantity and quality, plant vigor, and stand persistence. Although the relative importance of each pest varies with the geographic region of the country, local environmental conditions, and harvest management, only a relatively few insect species are responsible for the majority of pest damage sustained by alfalfa grown in the United States (Manglitz and Ratcliffe, 1988).

The following insects are on the chlorpyrifos 4E label: alfalfa and Egyptian alfalfa weevils; the potato leafhopper; and several aphid species. In addition, chlorpyrifos is also registered for controlling several occasional alfalfa pests: southern corn rootworm; migratory grasshoppers; differential, redlegged, twostriped, and clearwinged grasshoppers; alfalfa blotch leafminer; alfalfa looper; army and variegated cutworms; fall armyworm; redbacked, pale western, dingy, and bristly cutworms; yellowstriped armyworm; alfalfa, tarnished, and rapid plant bugs; and meadow spittlebug.

Chlorpyrifos 4E application rates range from 0.25 to 1.0 lb a.i. per acre. Chlorpyrifos 4E has label restrictions regarding the use of this chemical on grazing land as well as restrictions concerning the number of chlorpyrifos 4E applications that can be made each season. Chlorpyrifos 4E may be applied through sprinkler irrigation systems.

PEST INFESTATION AND DAMAGE

Primary Pests

Alfalfa weevil complex—The alfalfa weevil complex, which includes the alfalfa weevil, *Hypera postica* (Gyllenhal); the Egyptian alfalfa weevil, *Hypera brunnipennis* (Boheman); and the potato leafhopper, *Empoasca fabae* (Harris) are the major pests that require management in U.S. alfalfa production.

Damage from infestations of alfalfa weevil is generally associated with the first cutting and stubble stage of the second cutting of alfalfa, whereas damage from potato leafhopper adults and nymphs is generally associated with second or third cutting of alfalfa (Manglitz and Ratcliffe, 1988).

The alfalfa weevil inhabits and damages alfalfa grown in all areas of the United States. However, according to Schroder and Metterhouse (1980), biological control agents have greatly reduced the impact of alfalfa weevil in the Eastern United States. Adult weevils overwinter in alfalfa fields, with eggs oviposited in alfalfa plant stems during the spring in Northern States and from fall through spring in the Southern States. Growers in Southern States have more difficulty managing alfalfa weevils than growers in Northern States. The extended ovipositional period in the South leads to greater larval numbers, and the time period during which larvae actively feed is longer in the South. These factors account for the severity of alfalfa weevil damage and management difficulties in the Southern United States. This insect is univoltine in most regions of the United States. The larval stage causes the majority of damage by feeding on interveinal leaf tissue. In the Southern and Western United States, the alfalfa weevil annually damages the initial spring growth of alfalfa and may retard second growth (Manglitz and Ratcliffe, 1988).

The alfalfa and Egyptian alfalfa weevils overlap in range in the western portion of the Nation, although in California the Egyptian alfalfa weevil tends to infest warmer, coastal, or low desert areas, whereas the alfalfa weevil inhabits the cooler, higher altitude areas (Anonymous, 1985). Although behavioral and range differences exist among these two species in California, results from recent genetic studies suggest that only the alfalfa weevil is found throughout the United States (Manglitz and Ratcliffe, 1988).

Potato leafhopper—The potato leafhopper is a primary pest of alfalfa in the Midwestern and Eastern United States (Cuperus et al., 1983). The adult of this small, pale-green, wedge-shaped, multivoltine insect is approximately 3 mm long and will readily jump or fly. Nymphs look similar to adults, although they lack wings and are capable of moving rapidly sideways on the host plant when disturbed. Poos and Wheeler (1943, 1949) found that the polyphagous feeding behavior of the potato leafhopper allowed for this insect's development on more than 200 species of wild and cultivated plants. Both adults and nymphs feed on alfalfa by piercing stems and leaves and removing juices from host plants. Feeding by potato leafhopper adults and nymphs on alfalfa may result in yellowing of plant tissue called "hopperburn" (Ball, 1919), stunting of host plants (Hollowell et al., 1927), and reducing yield and quality (Kindler et al., 1973). Medler (1957), using information from a 1950 North Central Regional Technical Committee on Entomology, first reported the migration of potato leafhopper from overwintering sites in the Gulf Coast States into the Midwest and Eastern regions of the country. Pienkowski and Medler (1962) correlated the migration and seasonal occurrence of this pest with synoptic weather conditions common during spring. Weather patterns will dictate specific arrival times of potato leafhopper in Midwestern and Northern States (Peterson et al., 1969). The migrant spring populations are economically important populations that often develop by the second or third alfalfa cutting.

Secondary Target Pests

Aphids—Several aphid species occasionally cause economic damage to alfalfa. The pea aphid, *Acyrthosiphon pisum* (Harris), is the most common aphid affecting alfalfa and can be found throughout the United States. Reductions in apical growth, flowering, and seed yield may result from terminal feeding by large numbers of pea aphids (Klostermeyer, 1962).

Western States often experience outbreaks of spotted alfalfa aphid, *Therioaphis maculata* (Buckton) and blue aphid in alfalfa production areas. Leaf loss, seedling mortality, and contamination of alfalfa with honeydew may result from spotted alfalfa aphid infestations (Manglitz and Ratcliffe, 1988). Davis et al. (1974) published a bibliography of the spotted alfalfa aphid. The blue aphid can be found in most Western States, but is especially damaging to alfalfa in Oklahoma in early spring (Berberet et al., 1983). According to Stanford et al. (1980), damage from blue aphid may include stunted plants, leaf chlorosis, and leaf loss.

Other secondary pests—Several other secondary pests are associated with occasional damage of alfalfa. Those listed on the chlorpyrifos 4E label include the southern corn rootworm, *Diabrotica undecimpunctata howardi* Barber; grasshoppers; alfalfa blotch leafminer, *Agromyza frontella* (Rondani); alfalfa looper, *Autographa californica* (Speyer); various armyworms and cutworms, plant bugs, and spittlebugs. Manglitz and Ratcliffe (1988) reported that cutworm species are the most damaging of the secondary pests. The variegated cutworm, *Peridroma saucia* (Hubner) and yellowstriped armyworm, *Spodoptera ornithogalli* (Guenee) are distributed throughout the United States, whereas the army cutworm, *Euxoa auxiliaris* (Grote) and redbacked cutworm, *Euxoa ochrogaster* (Guenee) are found only in the Western section of the country. Economic infestations of secondary pests are generally regional or local in occurrence, and are regularly associated with differences of weather, weed density, plant species diversity, and harvest management. Many of these occasional alfalfa pests can be controlled through a variety of methods, including cultural techniques, resistant varieties, biological control, and chemical control when necessary (Armbrust et al., 1980).

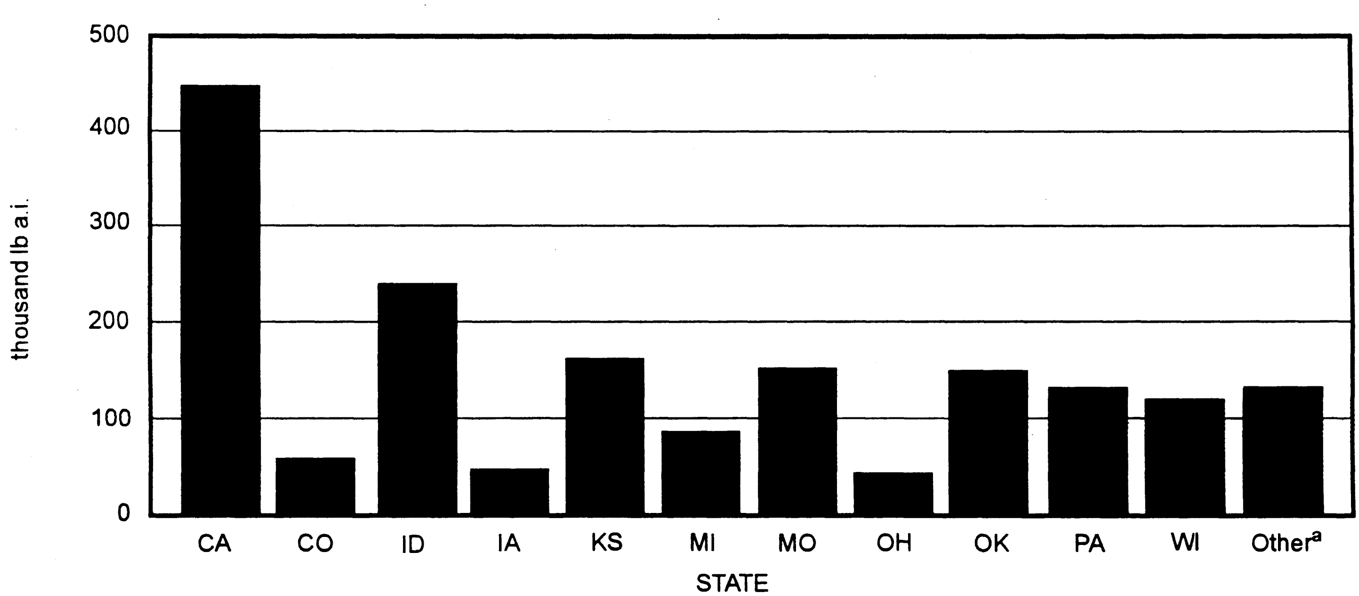
PEST MANAGEMENT

Current Chemical Usage

The January 1990 Annual Crop Summary conducted by the National Agricultural Statistics Service (NASS) indicates that current alfalfa acreage in the United States is approximately 26 million acres. According to a NAPIAP pesticide use questionnaire returned by 22 States, insecticides were used on 38.4 percent of the alfalfa acreage annually. The pests that are targets for alfalfa insecticide application were alfalfa weevil (52 percent of the applications), potato leafhopper (17 percent), and other pests (31 percent).

Chlorpyrifos is used on 2.3 million acres annually to control alfalfa pests. Twenty-two States reported chlorpyrifos usage, totalling 1.77 million lb of a.i. California was the largest user of chlorpyrifos on alfalfa (Figure 5). The usage in California

Figure 5. Chlorpyrifos 4E Use on Alfalfa, 1987-89 Average [Total = 1,776,969 lb a.i.]



[a]Other = AR,IN,KY,MT,NE,NV,NY,SD,UT,WA,WY

and 10 other States accounts for 92 percent of the national chlorpyrifos usage on alfalfa.

Assuming that chemical alternatives to chlorpyrifos remain registered, the cancellation of chlorpyrifos on alfalfa would not result in a reduction of yield or quality in 63.6 percent (14 of 22) of the reporting States. The States where alfalfa yield would be reduced by the loss of chlorpyrifos are (pest and percent yield reduction in parentheses): California (alfalfa weevil, 0-10 percent), Idaho (redbacked cutworm, 95 percent), Indiana (potato leafhopper, 0-10 percent), Kansas (alfalfa weevil, 0-3 percent), Kentucky (alfalfa weevil, 0-5 percent), Oklahoma (alfalfa weevil, 0-5 percent; aphid complex, 0-7 percent; army cutworm, 0-15 percent; variegated cutworm, 0-6 percent), Utah (alfalfa weevil, 0-5 percent), and Washington (aphid complex, 0-3 percent).

Chemical Alternatives to Chlorpyrifos

Registered chemical alternatives to chlorpyrifos for control of primary pests (alfalfa weevil, Egyptian alfalfa weevil, potato leafhopper) are azinphos-methyl, carbofuran, carbaryl, diazinon, dimethoate, malathion, methidathion, methomyl, methoxychlor, methyl parathion, encapsulated methyl parathion, permethrin, phosmet, and trichlorfon. Constraints of the various chemical alternatives were expressed on survey responses from several States. The following is a summary of the comments offered by Dr. Vernon E. Burton, Extension Entomologist Emeritus, University of California-Davis, who best described the situation: Chlorpyrifos 4E is often the insecticide of choice in California and the Midwest when alfalfa weevil and aphid populations increase to outbreak levels simultaneously. Chlorpyrifos exhibits a high degree of control for both of these pests. Equally effective is carbofuran, although its use is limited by bird and human toxicity concerns. Phosmet will control weevil populations, but is ineffective against aphids. Malathion and methoxychlor are less effective than other products against weevils and aphids, and are not commonly used east of the Rockies. Methyl parathion is very toxic to mammals, whereas encapsulated methyl parathion is associated with honey bee kills. Alfalfa weevil and aphids are killed by diazinon, although diazinon is not as effective as chlorpyrifos or carbofuran.

In the Southern States, where heavy alfalfa weevil infestations may require two or more insecticide applications per cutting to obtain control, the loss of chlorpyrifos would seriously limit the ability of producers to rotate insecticides on a single cutting of alfalfa.

Alfalfa specialists from Eastern States expressed less concern about the loss of chlorpyrifos for control of potato leafhopper infestations. Several respondents reported that dimethoate and permethrin are equal or superior to chlorpyrifos for control of potato leafhopper. However, this trend was less evident in several Midwestern States where chlorpyrifos and permethrin were reported preferable to dimethoate for controlling potato leafhopper. Respondents throughout the country indicated concern regarding the possible loss of chlorpyrifos from alfalfa pest management options due to this chemical's effective role in resistance management and alfalfa IPM programs.

Comparative Performance

The performance of chlorpyrifos in comparison with that of alternative insecticides varies, depending on target species and region of use. Chlorpyrifos and carbofuran together account for more than one-third of the total alfalfa acres treated in the United States. The majority of chlorpyrifos usage is for controlling the alfalfa weevil complex in Western States and the alfalfa weevil in Southern and Midwestern States. Alfalfa weevil applications generally occur prior to the first cutting of the season.

Respondents report that the efficacy of chlorpyrifos and carbofuran is similar for alfalfa weevil control in two States (CA, SD), although other States reported increases in performance of carbofuran, ranging from 1 to 50 percent better (AR, CO, IN, IA, KS, KY, MI, MO, MT, NE, NV, OH, OK, PA, UT, WY, [mean = +14.5 percent]). Chlorpyrifos costs approximately $9.45 per acre (0.75 lb a.i. per acre), whereas carbofuran costs approximately $7.31 per acre (0.5 lb a.i. per acre) for controlling alfalfa weevils. Unlike carbofuran, chlorpyrifos is classified as a General Use insecticide; users need not be certified to have a private applicator's status in order to purchase and use the product. Other insecticides, except for methyl parathion, exhibit reduced performances when compared to chlorpyrifos. Although the performance of methyl parathion is approximately equivalent to chlorpyrifos, concerns about high mammalian toxicity and user safety limit its use. Encapsulated methyl parathion (Penncap-M) is less hazardous to use than parathion, but is extremely toxic to bees.

Chlorpyrifos 4E is labeled for controlling the potato leafhopper, which is a migratory pest of second and third alfalfa crops. A total of nine States reported performance data for chlorpyrifos 4E against potato leafhopper. In the Eastern United States, dimethoate consistently performs as well as or better than chlorpyrifos for potato leafhopper control (IN, MI, NY, OH, PA [mean = +21.2 percent]). However, the reliability of dimethoate's supply during the season and especially in outbreak situations is poor. The Eastern States found permethrin performance higher (mean = +1.4 percent) than that of chlorpyrifos and carbofuran performance slightly lower (mean = -2 percent).

Nonchemical Alternatives

Nonchemical alternatives for control of alfalfa weevil, potato leafhopper, aphids, and various occasional pests of alfalfa have met with variable success. Biological control of alfalfa weevils has greatly reduced problems with this pest in Eastern States, where parasites were first released (Schroder and Metterhouse, 1980). Additionally, Manglitz et al. (1981) reported that parasite activity, coupled with late spring freezes, reduced alfalfa weevil numbers to below economic levels for several years in Nebraska. The alfalfa weevil is susceptible to a fungal disease, *Erynia* spp., that is found throughout most of the United States (Puttler et al., 1978). However, this disease rarely controls alfalfa weevil larvae before they reach late instars, and only after much feeding damage has occurred (Wilson, 1985). Other fungal pathogens have been more effective in the control of pea aphid (MacLeod, 1955), spotted alfalfa aphid (Hall and Dunn, 1957), clover leaf weevil, *Hypera punctata* (Fabricius), and the alfalfa caterpillar *Colias eurytheme* Boisduval (Hall, 1953; Hall and Stern, 1962; Stanford et al., 1968). However, outbreaks of these pests have continued to occur, requiring chemical treatments to prevent significant crop losses. *Bacillus thuringiensis* Berliner, a bacteria in several commercially available biological insecticides, was found to be as effective as some insecticidal treatments for controlling alfalfa caterpillars (Hall and Stern, 1962, Stanford et al., 1968).

Arthropod predators can also reduce populations of insect pests. Pea aphid is frequently controlled by a complex of lady beetle species, although the convergent lady beetle, *Hippodamia convergens* Guerin-Meneville (Simpson and Burkhardt, 1960), and the sevenspotted lady beetle, *Coccinella septempunctata* L. (Angalet et al., 1979) are credited as the most efficient aphid predators. Other predators of alfalfa pests include lacewings, damsel bugs, insidious flower bugs, stink bugs, mites, ground beetles, syrphid flies, assassin bugs, and tachinid flies (Edward, 1988).

Cultural methods that traditionally have reduced alfalfa pest problems include early or delayed harvest, flaming and grazing of green alfalfa tissue, and burning of old growth. The harvest of alfalfa in the early bud or early bloom stages was found to partially prevent the buildup of alfalfa weevil, potato leafhopper, and other arthropod pests (Smith, 1956, Pienkowski and Medler, 1962). Flaming of alfalfa was used with partial success in the 1930's and again in the 1960's to reduce early spring infestations of aphids (Blanchard et al., 1933) and alfalfa weevil (Blickenstaff, 1965; Bishop and Pienkowski, 1967), respectively. High fuel costs in the 1970's restricted the use of flaming, although current research with high-efficiency flaming equipment is being conducted by the Agricultural Engineering and Entomology departments at Kansas State University (Randall Higgins, 1991, personal communication). The most efficient use of fire as a pest control technique was demonstrated by Lilly and Hobbs (1962) and Tippens (1964) when they removed old growth plant tissue by burning dormant alfalfa during winter or early spring. Gyrisco (1958) reported that removal of spring alfalfa growth by grazing was an efficient technique for controlling some alfalfa pests. Alfalfa stands containing other types of vegetation are being investigated as to the impact these mixed stands have on insect pest numbers. Lamp et al. (1984) found reduced densities of potato leafhopper in alfalfa plots containing weeds compared to weed-free plots. Similarly, Lamp (1991) reported reduced leafhopper densities in oat-alfalfa interseedings. However, growers have been slow to adopt this tactic, since the interseeding of grass or other plants with alfalfa will reduce yield and stand longevity, which reduces grower income and feed production.

Another insect management tool is the use of resistant alfalfa cultivars. Blanchard and Dudley (1934) first discussed the use of resistant alfalfa cultivars for controlling pea aphid approximately 60 years ago. This management technique of developing resistant plant varieties provides producers with long-term, low-cost insect control (Manglitz and Ratcliffe, 1988). Ratcliffe (1979) documents recent alfalfa cultivars and the insect species these cultivars impact. Maxwell and Jennings (1980) presented a detailed review of plant breeding and insect control. Sorensen et al. (1988) reviewed recent literature concerning the use of resistance for control of forage insect pests. However, there are no true potato leafhopper-resistant cultivars available to date.

Early harvest of alfalfa is listed as a possible pest management technique by several States responding to the survey. Although early harvest is used to reduce alfalfa weevil and potato leafhopper numbers, the effectiveness of this cultural management option depends on accurate monitoring, proper timing of harvest, and environmental conditions in the field before and after forage removal. Because this pest control technique produces variable results and uncertain economic returns, most respondents indicated that the benefits of early harvest could not accurately be compared to insecticidal treatments. However, most respondents thought that early harvest might be a valuable cultural management tool in IPM programs when an alfalfa field is carefully monitored.

Similarly, biological control has proven to be an effective tool in the integrated approach to pest management. Much of the reduction in alfalfa weevil problems experienced by the Eastern States must be attributed to the activities of introduced biological control agents (Schroder and Metterhouse, 1980). However, similar reductions in alfalfa weevil numbers have not been documented for other regions of the country. As introduced biological agents increase in population densities—and the impact of these agents is combined with naturally occurring parasites, predators, and pathogens—alfalfa weevil reductions may occur.

Pesticide Resistance

The potential for major alfalfa insect pests developing resistance if chlorpyrifos use were canceled would be moderate for alfalfa weevil and low for potato leafhopper and aphids. The available alternative insecticides for use on alfalfa pests include products from the organophosphate, carbamate, and pyrethroid classes of insecticides. Chlorpyrifos and carbofuran account for approximately 50 percent of all insecticide use on alfalfa. In the South and Midwest, both compounds share the market for alfalfa weevil control. In the East, dimethoate is the preferred insecticide for controlling potato leafhopper; however, both chlorpyrifos and carbofuran are used by many producers in this region. Western States use chlorpyrifos and carbofuran for controlling Egyptian alfalfa weevil, alfalfa weevil, aphids, and various cutworms.

Many survey respondents noted that carbofuran would replace chlorpyrifos for alfalfa weevil control if chlorpyrifos were no longer available. If one insecticide becomes the dominant product used for insect control, then the risk of developing resistance to that compound greatly increases. Dimethoate would remain the insecticide of choice for potato leafhopper in the Eastern States, whereas the use of carbofuran, permethrin, and dimethoate for potato leafhopper problems would increase in Midwestern and Southern States.

Impact on Beneficial Insects

The loss of the chlorpyrifos registration on alfalfa would not have an impact on pollinating insects unless the use of encapsulated methyl parathion (Penncap-M) increases. The label for methyl parathion lists a specific warning regarding extreme toxicity to honey bees.

Integrated Pest Management

Rabb (1972) describes integrated pest management (IPM) as the intelligent selection and use of pest control actions that ensure favorable economic, ecological, and sociological consequences. IPM can be effectively implemented in alfalfa production systems, and some producers are already doing so. Alfalfa producers can utilize numerous pest control tactics that provide long-term, economical pest management, while minimizing crop losses and disruption to the environment (Anonymous, 1985). Metcalf and Luckman (1982) list general categories of insect control methods as follows: cultural, mechanical, physical, biological, chemical, genetic, and regulatory. Resistant cultivars are best used in an integrated pest management program that combines resistant cultivars with cultural, chemical, and biological methods of control (Maxwell and Jennings, 1980). A successful IPM program incorporates many nonchemical methods to control problem insects and combines these methods with the judicious use of chemical insecticides. Researchers are currently investigating pest control tactics that further reduce insecticidal applications.

IPM strategies are being implemented to manage alfalfa and Egyptian weevils. Wood et al. (1978) compiled a bibliography for both of these insects. Economic thresholds for alfalfa weevils vary among States; however, general thresholds on the average of 1 to 2 larvae per stem or approximately 20 larvae per sweep are used in most States. Economic threshold levels may change depending on plant height, stand vigor, plant stage, and the presence of biological control agents. Several States have developed models that predict economic outbreaks of this pest with some success.

IPM strategies are also used to manage the potato leafhopper. According to Simonet and Pienkowski (1979), the timing of alfalfa harvest may significantly influence the survival and subsequent damage caused by potato leafhopper nymphs. The economic threshold for this pest on alfalfa is based on the number of insects present per unit area and the average plant height of the alfalfa (Wilson, 1985). A bibliography for potato leafhopper was compiled by Gyrisco et al. (1978). Pennsylvania researchers are currently testing a model (PennPlex) for predicting potato leafhopper population dynamics and economic outbreaks (Hower and Calvin, 1991).

The pea aphid is also managed under IPM. Although economic thresholds vary from State to State, Cuperus et al. (1982) determined 114 pea aphids per day per stem to be the economic threshold in Minnesota. Harper et al. (1978) published a bibliography for the pea aphid. Because pea aphid and alfalfa weevil population densities frequently reach economic levels simultaneously, pea aphid populations are generally controlled by insecticide applications directed at alfalfa weevil larvae.

FUTURE PEST MANAGEMENT OPTIONS

Several second and third generation pyrethroid insecticides have been field-tested and await EPA registration for use on alfalfa pests. Some of these insecticides have been under consideration for years. Pyrethroid use was registered on alfalfa since the initial registration of permethrin in 1988.

Management of alfalfa weevil and potato leafhopper should improve as researchers come to better understand the biology, behavior, and host plant interactions associated with each of these pest species. As producers' acceptance of IPM increases, alfalfa pest management through these practices will become more efficient.

For the foreseeable future, however, chemical insecticides will continue to play a major control role until economically viable alternative control technologies are developed and their efficacy is documented. Survey respondents expressed concern that safe and effective insecticides are being lost for alfalfa pest management before reliable and economically competitive alternative control technologies have been developed.

If the registration of chlorpyrifos 4E on alfalfa is canceled, it is estimated that the carbofuran market share will increase significantly for alfalfa weevil control, whereas dimethoate and permethrins would increase in use for potato leafhopper control. Many States noted that the loss of chlorpyrifos would be significant to alfalfa producers, since it is a broad spectrum General Use insecticide that is readily available to producers, and its use is perceived to be safe as well. Some States estimate an increase in pesticide use on alfalfa if chlorpyrifos were unavailable because chlorpyrifos currently controls multiple alfalfa pest species with a single application. Without chlorpyrifos as a management option, two insecticide applications would be required to control concurrent pest infestations, such as alfalfa weevil and pea aphid, or alfalfa weevil and cutworms.

SUMMARY

Chlorpyrifos is an important part of alfalfa pest control programs in the United States. Of the 26 million acres of alfalfa grown in this country, approximately 8.7 million acres (34 percent) are treated annually with foliar insecticides. The alfalfa weevil complex, potato leafhopper, and other insect pest problems account for approximately 52 percent, 17 percent, and 31 percent of total acres treated, respectively. Chlorpyrifos and carbofuran together account for more than half of the total amount of insecticide applied for alfalfa pest control.

Survey respondents agree that chlorpyrifos and carbofuran are the most efficacious insecticides for controlling the alfalfa weevil and the Egyptian alfalfa weevil. The efficacy of chlorpyrifos for controlling the potato leafhopper differs by region, but chlorpyrifos remains an effective management option for controlling this pest throughout the alfalfa production regions of the Nation. Evidence is limited as to the impact on yield, producer income, or commodity prices that would occur if chlorpyrifos were no longer available for control of alfalfa insects. Alfalfa specialists speculate that several changes would occur if the registration of chlorpyrifos were canceled. These changes include:

1. Producer discontent would increase with the loss of an effective, General Use insecticide that has a substantial share of the insecticide market for alfalfa weevil and potato leafhopper control.

2. Carbofuran use would increase for alfalfa weevil control, whereas dimethoate, permethrin, and carbofuran would replace chlorpyrifos use for potato leafhopper control. Carbofuran (4F) FL is a category I Restricted Use insecticide.

3. The potential for the development of pest resistance would increase moderately since the number of alternative insecticides available for pest management would be reduced.

4. An increased pesticide load would occur on alfalfa since applications of two or more insecticides will be required to control concurrent pest infestations that are now controlled by a single chlorpyrifos application.

5. Early harvest (7 to 10 days), biological control, resistant cultivars, and other nonchemical control methods would be used more frequently as alternative control techniques are effectively incorporated into IPM programs. However, insecticides will remain essential components of IPM programs for the foreseeable future.

The use of IPM programs for alfalfa production will increase in the future as new management techniques are developed and traditional techniques are refined. Alfalfa producers will rely less on chemical controls, but will require better nonchemical preventive techniques, pest detection methods, and models for predicting pest population dynamics. Once pest populations reach or exceed economic threshold levels, appropriate chemical and nonchemical control techniques will need to be employed. Educating producers is the key element in the acceptance and success of IPM programs for alfalfa pests.

Chlorpyrifos Use on Clover Seed Crop

John Rinehold and Jeffrey J. Jenkins

INTRODUCTION

Table 9 contains label information from the Pesticide Label Information Retrieval System (PLIRS) and the 1991 Pacific Northwest Insect Control Handbook regarding insecticides registered on clover and seed crop. The clover aphid is the primary pest that attacks clover crops. Most of the clover crops grown in the United States are in the Pacific Northwest—Washington, Oregon, and Idaho. Less viable chemical alternatives to chlorpyrifos 4E treatments for controlling clover aphid are disulfoton and oxydemeton-methyl 2E.

PEST INFESTATION AND DAMAGE

The clover aphid, *Nearctaphis bakeri* (Cowen), attacks clover grown for seed in the central Willamette Valley of western Oregon, Malheur County in eastern Oregon, Yakima Valley and Columbia Basin of eastern Washington, and the Ada-Canyon County region in southern Idaho. Leffel et al. (1989) conducted six trials over a 3-year period for commercial red clover in the northern Willamette Valley (Table 10). These trials indicate that controlling aphids increased seed yield compared with untreated plots.

In a separate study on red clover, Leffel et. al. (1989) showed chlorpyrifos 4E provided significantly better control than oxydemeton-methyl 2E (Table 11). Chlorpyrifos 4E also reduced the aphid population to below the check levels throughout the evaluation.

Johansen (1960) calculated the reduction in red clover seed yields in 1957 and 1958 studies conducted in the Yakima Valley. He found that 6.5 to 8.8 percent of the seed yield reduced by clover aphid was caused by a loss of individual seed weight. Approximately 60 percent of seed loss from the aphids was caused by reduction in weight and 40 percent by reduction in the number of seed heads. The criteria developed by Johansen for determining severity of clover aphid infestations are found in Table 12.

Table 9. Insecticides registered on clover and clover seed crop, rates applied, and number of labels available

Pest	Chemicals Registered	Rates Applied	Labels
Clover Seed Crop			
Aphids	chlorpyrifos 4E	0.5 - 1.0 lb/acre	1
	oxydemeton-methyl 2E	0.5 lb	1
	methyl parathion 4	0.25 - 0.5 lb	5
	aqua malathion 8 lb	1.0 - 1.25 lb	1
Clover			
Aphids	diazinon	0.5 lb	20
	parathion	0.5 - 0.75 lb	18
	azinphos methyl	0.25 - 0.5 lb	3
	methyl parathion	0.25 - 0.5 lb	8
	malathion	1.0 - 1.5 lb	18
	mevinphos	0.25 lb	6
	ethyl-methyl parathion 6-3	0.25 - 0.67 lb	7
	disulfoton granules	1.0 lb	2
	pyrellin EC (rotenone + pyrethrins) (Webb Wright)		2
	malathion - methoxychlor (Platte)	2.0 - 3.0 lb	1

Table 10. Percent increase in seed yield over untreated check plots when controlling aphids

Chemical Treatment	1987[a]	1988[b]	1989[b]	Average[c]
chlorpyrifos 4E (1.0 lb/a)	8	30	22	22.2
chlorpyrifos 4E (0.5 lb/a)	16	21	22	20.0
oxydemeton-methyl (0.5 lb/a)	6	5	9	6.6

[a]Data from one location.
[b]Data averaged from two locations.
[c]Average of all locations.

Table 11. Seed yield of red clover at two locations following treatment for control of clover aphids, 1989.

Treatment	Field 1	Field 2
	lbs/acre	
chlorpyrifos 4E 1.0 lb/a	856	651
chlorpyrifos 4E 0.5 lb/a	803	680
oxydemeton-methyl 0.5 lb/a	748	592
untreated check	744	505

Table 12. Criteria for determining severity of infestation by clover aphids, based on number of aphids per 10 heads or stipules[a]

Extent of Infestation	Weeks After Hay Cutting				
	3	4[b]	5[b]	6	7
Light	0 - 5	[c]0 - 10	0 - 15	0 - 50	0 - 150
Medium. . .	10 - 25	[c]15 - 50	20 - 100	60 - 250	200 - 750
Heavy	+25	+75	+200	+500	+1000

[a]Based on populations in central Washington, 1956-59.
[b]Aphids moving from stipules to heads of clover plant.
[c]Insecticide treatment recommended if medium or heavy population is developing.

The clover aphid hides in protected places on the plant and may be found in great numbers in the blossoms and beneath the leaf stipules. These insects prefer red and alsike clover, but will infest other types as well. Adults and nymphs suck plant juices from the stems, leaves, and flower buds. Insect feeding on clover causes blossoms to drop or makes these flowers unattractive to pollinators. This feeding also stunts plants, resulting in small leaves. The most noticeable damage is caused by honeydew produced by the aphids, which interferes with harvesting. Seed caked with honeydew is difficult to clean. High temperature does not have a pronounced effect on the aphid populations, because they are sheltered by the clover. Moreover, the clover aphid is predominantly a hot weather insect.

PEST MANAGEMENT

Current Chemical Usage

Chlorpyrifos 4E SLN (Special Local Need) registration and oxydemeton-methyl 2E are the two important registered pesticides for controlling aphids on clover seed crops. Table 13 shows the relative use of alternative insecticides in Oregon, Washington, and Idaho.

Chemical Alternatives to Chlorpyrifos

Oxydemeton-methyl 2E is used to a small extent to control the clover aphid in eastern Washington as well as in the Willamette Valley. In the trial shown in Table 11, the oxydemeton-methyl 2E treatments increased seed yields slightly above

Table 13. Three-year average for chlorpyrifos 4E and alternative chemical treatments in Idaho, Oregon, and Washington

Chemical	Percent Fields Treated	Primary Target Pest	Impact if chlorpyrifos 4E were not available and a substitute used	
			Region	Percent Yield
chlorpyrifos 4E	[a]+50	Aphids	Willamette Valley	----
oxydemeton-methyl	20	Aphids	Willamette Valley	[a]-10 to -20
chlorpyrifos 4E	[b]0	Aphids	Ontario County	----
chlorpyrifos 4E	[c]0	Aphids	Ada-Canyon Counties	----
chlorpyrifos 4E	[d]0	Aphids	Columbia Basin	----
metasystox-R		Aphids	Columbia Basin	
disulfoton 15G		Aphids	Columbia Basin	[4]0
chlorpyrifos 4E	[d]0	Aphids	Yakima Valley	----
metasystox-R		Aphids	Yakima Valley	
disulfoton 15G		Aphids	Yakima Valley	[4]0

[a]John Leffel
[b]Ben Simko
[c]Darrell Bowels
[d]Butch Johansen

Table 13 contains the relative use in Oregon, Washington, and Idaho. It is a compilation of survey information provided by: John Leffel, retired Washington County Extension Agent (Oregon); Ben Simko, Malheur County Extension Agent (Oregon); Darrell Bowels, Canyon County Extension Agent (Idaho); Butch Johansen, Cal-West Seed Company, (Othello, WA).

the untreated check plots. Malathion 8E is not satisfactorily efficacious on aphids and will not be retained for use on clover except for ultra low volume (ULV) application. Disulfoton 15G is the preferred insecticide to control aphids on clover in eastern Washington.

Comparative Performance

Chlorpyrifos 4E and oxydemeton-methyl generally provide satisfactory aphid control for 3 to 4 weeks. Table 10 indicates that increases in seed yields were notably higher with the use of chlorpyrifos 4E treatments.

Nonchemical Alternatives

Aphid populations are reduced by many natural enemies, such as lady beetles, lacewings, syrphid larvae, and parasites. Rapid growth of clover crops in the spring reduces the possibility of aphid damage.

Impact on Beneficial Insects

Insecticides are rarely applied after the clover bud stage. As a result, the pollinating insects are not affected. During the 1989 clover insecticide trials, honey and bumble bees were also observed. No difference was noted in the bees' activity before or after the insecticide treatments (Fisher, personal communication, 1991).

Integrated Pest Management

In general, one application of chlorpyrifos 4E is required after hay cutting at the time bloom buds form. After this treatment, natural predators control the population of aphids for the remainder of the season. In almost all cases, these predators and parasites will keep the aphid population in check throughout the bloom and harvest of this crop.

SUMMARY

In the United States, nearly all clover seed crops are grown in Oregon, Washington, and Idaho. If chlorpyrifos 4E were no longer registered for clover seed crop, growers could use either oxydemeton-methyl (2E) and sustain a 15 percent yield reduction, or adjust their equipment for granular applications of disulfoton 15G. Both alternatives are Restricted Use insecticides, while chlorpyrifos is a less toxic General Use insecticide.

Chlorpyrifos Use on Corn

Gerald R. Sutter, John F. Witkowski, and Marlin E. Rice

INTRODUCTION

Corn, *Zea mays* L., is the major feed grain grown in the United States. Approximately 69 million acres of corn were planted annually during the years 1987 to 1989. Corn is grown in nearly every State, and 75 percent of this acreage is located in the 10 Midwestern Corn Belt States: Illinois, Indiana, Iowa, Michigan, Minnesota, Wisconsin, Nebraska, Ohio, Missouri, and South Dakota. States outside of the Corn Belt that reported significant acreages of corn (greater than 500,000 acres) were: Colorado, Georgia, Kansas, Virginia, Kentucky, Maryland, North Dakota, New York, North Carolina, Pennsylvania, Tennessee, and Texas.

Insecticides are used extensively in corn production to protect plants from an array of plant- and soil-based arthropod pests. In the majority of the U.S. corn-growing areas, the corn rootworm complex (the western corn rootworm and the northern corn rootworm) is of great importance economically, with nearly $1 billion in control costs and crop losses attributed to this pest complex annually (Metcalf, 1986). Consequently, the majority of insecticides used in corn production are applied to the soil at planting or occasionally at cultivation time to reduce feeding damage by the corn rootworm larvae.

This insecticide application practice offers the added benefit of attempting to reduce plant stand loss caused by a number of additional sporadic soil insect pests; for example, cutworms, wireworms, white grubs, Scarabaeidae, and others. Foliar sprays of post-planting applications are also employed for controlling the European corn borer and cutworms. Applications at planting and later in the season are likewise done over a significant acreage in those corn production areas of the country where the target pest(s) are not corn rootworm larvae. The target pests in these situations include three of the pests mentioned above (cutworms, wireworms, and white grubs), as well as a complex of other soil and foliar insects (specific to geography), and the European corn borer. A complete list of primary and secondary insect pests follows later in this chapter.

Chlorpyrifos 15G and 4E are registered for controlling the following pests of field corn, seed corn, popcorn, and sweet corn: northern, western, and southern corn rootworms; armyworms and cutworms; wireworms; grubs; billbugs; seedcorn maggot; lesser cornstalk borer; seedcorn beetle; flea beetles; symphylans; European corn borer; southwestern corn borer; fire ant; western bean cutworm; chinch bug; aphids; webworms; corn earworm; stalk borer; and grasshoppers. The methods and times of chlorpyrifos applications are tailored to the particular pest and include preplant broadcast, planting time (T-band, band, or in-furrow), and postplant band or broadcast application of either liquid or granular formulations. Chlorpyrifos 4E and 15G are registered to be applied by ground, air, or chemigation equipment.

PEST INFESTATION AND DAMAGE

Primary Pests

Corn rootworm complex—Feeding damage caused by larvae of the western corn rootworm, *Diabrotica virgifera virgifera* LeConte, and the northern corn rootworm, *D. barberi* Smith and Lawrence, is the greatest concern in insect pest management and plant protection of corn in the Midwest. Larvae inhabit the soil and feed almost exclusively on the roots of corn (Branson and Ortman, 1971). The impact of these pests on corn depends on many factors, such as soil type, soil fertility, precipitation, winter soil temperatures, cropping practices (rotation with nonhost crops, tillage, planting date), plant varieties, and various other agronomic practices (Levine and Oloumi-Sadeghi, 1991).

Corn rootworms are generally the major soil pests in fields where corn is grown continuously. Growers may culturally manage these pests by annually rotating corn with a nonhost crop. Growers who plant corn continuously on the same acreage typically apply a granular insecticide at planting or occasionally at cultivation time as a preventive measure to reduce larval feeding damage. The adult stage of this pest, a beetle, may be found in mid-summer foraging on corn. Generally, feeding damage by the adult is not of economic importance, except for silk clipping in seed corn, sweet corn, and popcorn. Insecticides are used to suppress beetle populations and reduce insect oviposition in corn. Use of these chemicals therefore causes lower larval populations the following year (Pruess et al., 1974). This control strategy is practiced only in some small geographical areas in the Corn Belt.

European corn borer—Infestations of European corn borer, *Ostrinia nubilalis* (Hubner), vary from year to year, depending on environmental conditions. However, infestations also may be influenced by planting dates and cultural factors, such as the types of tillage practices and the corn varieties grown. The European corn borer attacks plant tissue above ground, resulting in weakened stalks, reduced ear size, and dropped ears. The European corn borer can be univoltine, bivoltine, or multivoltine. In most areas of the Corn Belt, the European corn borer is bivoltine. Many biotic and abiotic factors affect populations of European corn borer; these factors can have a potential effect on corn production during any particular year (Showers et al., 1989c).

Black cutworm—The black cutworm, *Agrotis ipsilon* (Hufnagel), is a primary (but sporadic) pest in several States across the corn-growing regions of the United States, particularly in the Corn Belt States of Missouri, Iowa, Illinois, and Indiana. In some years this insect can be a pest of consequence over a much larger geographic area. The distribution and extent of infestations of this pest depend on cyclonic conditions affecting emigration of moths in early spring prior to planting (Showers et al., 1989a and 1989b). Infestations are influenced by moth density, previous cropping practices that affect crop residues, weed cover present at the time of moth flights, and soil moisture conditions.

Secondary Pests

Several insects are primary pests in certain regions of the country in some years, but not in other regions. Because their impact is sporadic and occurs in relatively limited geographic areas, these insects are classified as secondary. Examples include: wireworms, Elateridae; billbugs, Curculionidae; southwestern corn borer, *Diatraea grandiosella* Dyar; chinch bug, *Blissus leucopterus leucopterus* (Say); white grub, *Phyllophaga* spp.; and armyworms, Noctuidae.

Chinch bug infestations can be serious. However, these infestations are sporadic in localized areas of corn production in Nebraska, Kansas, Louisiana, Mississippi, Texas, and Oklahoma. A complete description of this pest's life history and damage is covered in Headlee and McColloch (1913) and Webster (1915). The southwestern corn borer is an important pest of corn in Mexico. This insect's range has expanded significantly in the United States from 1930 to 1970. The southwestern corn borer has gradually spread into 14 South Central States, and is presently considered an established pest below the 38 North latitude (Chippendale and Conner, 1989). In recent years, heavy, localized infestations of this insect have occurred in Texas, southwestern Kansas, southeastern Missouri, and west central Mississippi. Billbugs can be a serious problem in the Southern States (North Carolina, for example), particularly in years when corn planting is delayed. Infestations of several species of wireworm are probably more general throughout the United States and are extremely unpredictable.

Additional secondary pests include other species of cutworms, Noctuidae; seedcorn maggot, *Delia platura* (Meigen); seedcorn beetle, *Stenolophus lecontei* (Chaudoir); flea beetles, Chrysomelidae; stalk borer, *Papaipema nebris* (Guenee); lesser cornstalk borer, *Elasmopalpus lignosellus* (Zeller); fire ant, *Solenopsis geminata* (F.); Banks grass mite, *Oligonychus pratensis* (Banks); twospotted spider mite, *Tetranychus urticae* Koch; the western bean cutworm, *Loxagrotis albicosta* (Smith); and grasshoppers, Orthoptera.

PEST MANAGEMENT

Current Chemical Usage

Questionnaires were sent to personnel in 38 States with a corn base greater than 500,000 acres to determine pesticide use and product performance during the past 3 years. Performance of chlorpyrifos 15G and 4E were compared with alternative chemicals in field corn, seed corn, popcorn, and sweet corn production. The following discussion summarizes the responses for each of these categories:

Field corn: Chlorpyrifos 15G—Thirty-two States returned questionnaires indicating that of the 67.2 million planted acres of field corn, 28 million acres were treated with 30.5 million lb of insecticide for pest management. In the top 10 corn-producing States, 53.9 million acres of corn were grown, of which 17.6 million acres (32.7 percent) were treated with one of several registered granular insecticides for controlling primarily the corn rootworm. Additionally, 2.3 million acres (4.2 percent) were treated annually for control of the European corn borer. Other insects of lesser economic importance that are targeted for and controlled by the same management technologies are: cutworms, wireworms, billbugs, lesser cornstalk borer, seedcorn maggot, chinch bug, and white grub. Of all the acres treated, chlorpyrifos 15G was used on 6.9 million acres (24.6 percent). For usage details, see Figure 6. If chlorpyrifos 15G were not available, respondents indicated that approximately the same acreage would be treated. The present market share of chlorpyrifos would be divided proportionally among the other chemicals on the market.

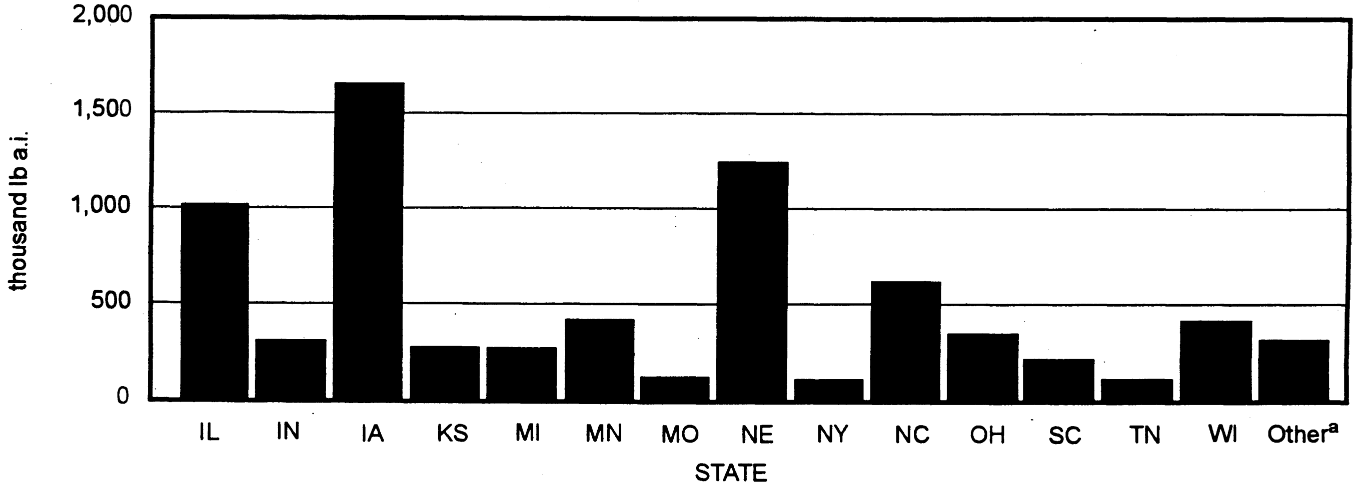
Field corn: Chlorpyrifos 4E—Twenty-two States returned questionnaires indicating that 9.5 million acres of corn were treated with either chlorpyrifos 4E or an alternative chemical to control a variety of pests, including European corn borer, stalk borer, cutworms, grubs, flea beetles, and grasshoppers. Chlorpyrifos 4E was used on 1.45 million (15.2 percent) of the treated acres (Figure 7).

Seed corn: Chlorpyrifos 15G–Seven States returned questionnaires regarding insecticide use on seed corn. Of the 380,000 acres grown in these States, a total of 326,000 acres were treated with 306,000 lb of a.i. (primarily for a complex of soil insects and European corn borer). Chlorpyrifos 15G was used on 65,000 acres; 79 percent of this insecticide's use was for controlling corn rootworm. If chlorpyrifos 15G were not available, approximately the same number of acres would be treated, with the acres treated divided proportionally among the available insecticides. Delaware (100 acres) indicated that the alternative chemicals were 2 percent less efficacious than chlorpyrifos 15G, while Georgia (50,000 acres) reported that seed treated with terbufos and carbofuran yielded 10 percent more than seed treated with chlorpyrifos 15G. Other States indicated no differences in performance among chemicals.

Seed corn: Chlorpyrifos 4E—Five States reported 72,000 lb of a.i. were used on 118,000 acres of seed corn. Chlorpyrifos 4E was used on 17,200 acres, of which 4,150 acres were treated for European corn borer and corn earworm, *Helicoverpa zea* (Boddie). If chlorpyrifos 4E were not available, the same acreage would be treated; however, the amount of a.i. applied would be reduced to 61,000 lb, primarily because more acres would be treated with pyrethroids.

Sweet corn: Chlorpyrifos 15G—According to the "USDA Vegetables 1989 and 1990 Summary," 204,000 and 472,000 acres of sweet corn were grown in the United States from 1987 through 1989 for fresh market and food processing, respectively. The 16 States that responded to the questionnaire reported growing 339,200 acres of sweet corn. More than half of these acres (162,000) were grown in Wisconsin. Chlorpyrifos 15G was used in the amount of approximately 49,000 lb a.i. on 24,900 acres (10 percent of the 244,345 acres treated). The majority of chlorpyrifos use was directed

Figure 6. Chlorpyrifos 15G Use on Field Corn, 1987-89 Average
[Total = 8,079,415 lb a.i.]

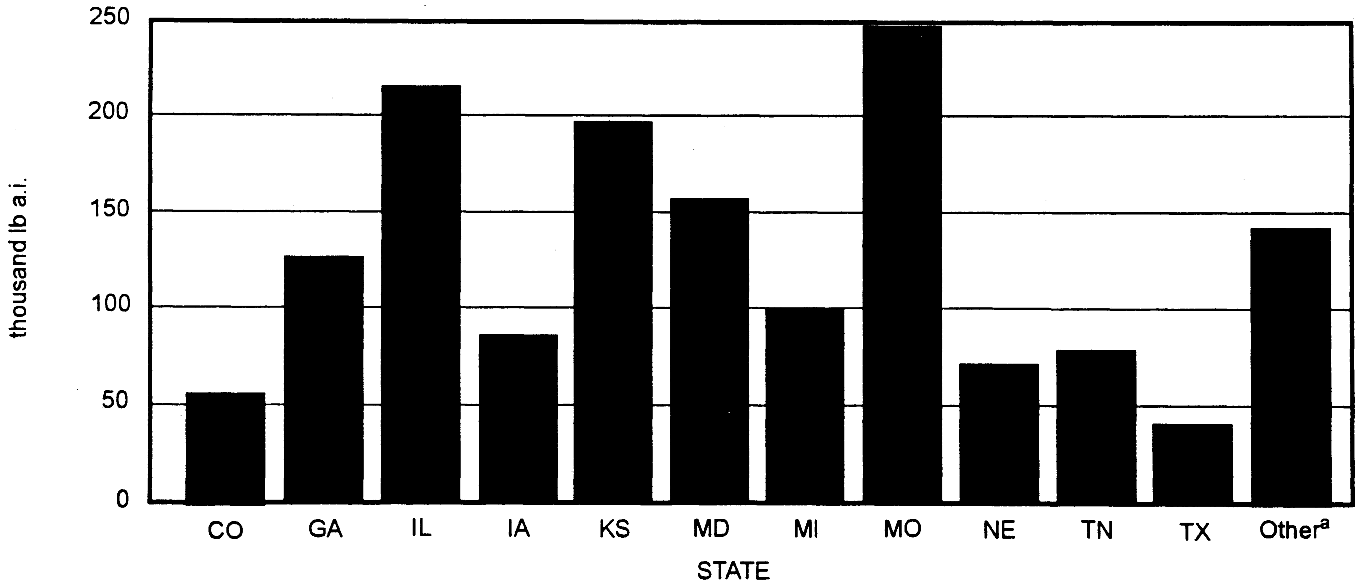


[a]Other = CO,DE,FL,GA,KY,LA,MD,MS,NJ,ND,OK,PA,SD,TX,UT,VA,WV,WY

at the soil insect complex, and the remaining use was for controlling the European corn borer. Chemical use and acreage treated if chlorpyrifos 15G were not available would not change significantly (232,800 lb a.i. would be used on 244,000 acres). Delaware (8,900 acres) indicated that alternative chemicals are 2 percent less efficacious than chlorpyrifos 15G, and New York (55,467 acres) rated permethrin 2 percent less efficacious than chlorpyrifos.

Sweet corn: Chlorpyrifos 4E—There were 163,300 acres of sweet corn grown in the 11 States that returned questionnaires on chlorpyrifos 4E use. There were 190,000 overall acres treated with 270,000 lb of a.i. Florida was the major user of insecticides on sweet corn; all 57,600 acres (primarily grown for the fresh market) were treated with an insecticide to control a complex of soil insects. Approximately the same number of acres were treated at least once with a foliar spray

Figure 7. Chlorpyrifos 4E Use on Field Corn, 1987-89 Average
[Total = 1,515,143 lb a.i.]



[a]Other = DE,FL,KY,MN,MS,NC,OH,OK,PA,SC,WV

to control borers, loopers, and other foliar pests. The number of treated acres (190,000) would remain approximately the same if chlorpyrifos 4E were not available. The amount of a.i. would be reduced to 207,000 lb, however, because pyrethroids, which would largely replace chlorpyrifos, are used at significantly lower rates of a.i.

Popcorn: Chlorpyrifos 15G—Five States reported that 98,000 acres of popcorn were treated with a general insecticide. For the control of soil insects (primarily corn rootworm larvae) and European corn borer, 14,800 acres were treated with chlorpyrifos 15G. Missouri (6,500 acres) reported that chlorpyrifos 15G is 10 percent more efficacious than alternative chemicals that were used for control of soil insects. The acreage treated and a.i. used would remain approximately the same if chlorpyrifos 15G were no longer available on the market.

Popcorn: Chlorpyrifos 4E—Three States indicated that of the 71,500 acres grown, 48,000 acres were treated with 37,000 lb a.i. Chlorpyrifos 4E was used on 9,400 acres, primarily for control of foliar insects. None of the States reported differences in efficacy among chemicals used. If chlorpyrifos 4E were no longer on the market, the same amount of acreage would be treated with 31,600 lb of a.i.

Chemical Alternatives to Chlorpyrifos

Chemical alternatives for control of corn rootworm larvae include: carbofuran, ethoprop, fonofos, phorate, tefluthrin, terbufos, and trimethacarb. The sale and use of granular carbofuran in corn is scheduled to end August 8, 1994. Most other granular formulations are presently under review by the EPA. Also, geographical differences in the available methods of application may limit the user's ability to apply alternative insecticides that are formulated differently.

Several insecticides are registered for control of corn rootworm adults, including carbaryl, carbofuran, dimethoate, malathion, esfenvalerate, parathion, permethrin, and SLAM. (SLAM is the trade name for a semiochemical-based product that contains 13 percent carbaryl by weight. There is currently no common name for this alternative).

Alternative insecticides registered for use against the European corn borer include granular formulations of carbofuran, fonofos, and permethrin, and several formulations of the biological insecticide containing *Bacillus thuringiensis* Berliner. Liquid formulations of insecticides registered for control of this pest include carbofuran, methyl parathion, permethrin, esfenvalerate, and products containing *Bacillus thuringiensis* Berliner. The sale and use of granular carbofuran is scheduled to end in August 1994.

Several alternative insecticides are available for controlling the black cutworm. Those applied at planting include: tefluthrin, permethrin, fonofos, and terbufos. The latter two chemicals are registered only for suppression of cutworms. Postplanting rescue treatments include esfenvalerate, fenvalerate, permethrin, and carbaryl.

Comparative Performance

Four States indicated differences in comparative performance of chlorpyrifos 15G and alternative chemicals. Assuming 100 bushels per acre of corn yields, and based on the acreages involved, experts in Delaware, Kansas, and North Dakota indicated a net loss of 548,000 bushels of grain if chemicals other than chlorpyrifos were used in certain instances. Conversely, Nebraska reported that if carbofuran were used in lieu of chlorpyrifos 15G for control of first generation European corn borer, yield would increase by 4.9 percent. In Nebraska, based on reported acreages treated with chlorpyrifos 15G and 100-bushel yield, growers would realize a yield increase of 1.7 million bushels by using carbofuran instead of chlorpyrifos. It should be noted, however, that the sale and use of carbofuran is scheduled to end on August 8, 1994.

Corn rootworm complex—Insecticide "performance" as a measure of corn rootworm control can be evaluated by several criteria: percentage of lodged plants; root-pull resistance; root-damage ratings; and yield (Mayo, 1986). For the past several decades, most entomologists have evaluated insecticide performance by comparing root-damage ratings of plants treated with various chemicals that were formulated and/or applied in different ways (i.e., banded or T-banded over the row or when placed in the seed furrow) with those plants extracted from untreated plots (Mayo, 1986). The extent which soil insecticides protect the roots from larval feeding can be established by removing roots from plots just after feeding is completed (usually in mid-July), visually determining the amount of feeding damage (scars and root pruning), and assigning a numerical value between 1 and 6 that corresponds to the level of root feeding and pruning by the corn rootworm larvae (Hills and Peters, 1971).

From 1985 to 1990, 62 reports in "Insecticide and Acaricide Tests" described the performance of planting-time applications of chlorpyrifos for control of rootworm larvae. Some of these reports included results from multiple trials. All of these reports included evaluation of the performance of chlorpyrifos by root-damage ratings: 19 percent included evaluation of percentage lodging, and 34, 21, and 3 percent of the reports included evaluation of yield, plant stand, and plant height, respectively. Table 14 summarizes how different formulations of chlorpyrifos and different methods of placement affected this chemical's performance in relation to the level of corn rootworm damage in "check" or untreated plots. The trials are divided into three categories: "high," when the check had a root-damage rating greater than 5 (on a 1 to 6 scale); "moderate," when the check had a mean root-damage rating between 4 and 5; and "low," when the check had a root-damage rating between 3 and 4. Because the so-called economic threshold is a root-damage rating of 3, trials in which the mean root-damage ratings in the check were less than 3 were not included in this table.

Chlorpyrifos applications had no effect on plant stand or plant height in any of the trials. Chlorpyrifos-treated plots had mean root-damage ratings that were greater than 3 more frequently in trials where the mean root-damage rating in the "check" was greater than 4. In nearly all the trials (31 of 34),

Table 14. Trials during a given year that a planting-time banded or in-furrow application of Lorsban 15G or 4E provided acceptable protection from rootworm larvae injury. Trials were separated into three categories based on Iowa's 1 - 6 root-damage rating of the untreated checks. Number of trials represented are in parentheses.

Damage Category[a]	Acceptable Protection[b]	1985	1986	1987	1988	1989	1990
HIGH							
	Root						
	15G banded......	1(2)	3(3)	3(4)	2(5)	3(5)	6(6)
	15G in-furrow.....	1(1)	0(1)	1(1)	-	-	-
	4E banded.......	-	0(1)	-	0(1)	0(4)	-
	Lodging						
	15G banded......	1(1)	1(1)	3(3)	-	1(1)	3(3)
	15G in-furrow.....	1(1)	1(1)	1(1)	-	-	-
	4E banded.......	-	1(1)	-	-	-	0(1)
	Yield						
	15G banded......	1(1)	-	-	0(1)	0(1)	1(1)
	15G in-furrow.....	-	-	-	-	-	-
	4E banded.......	-	-	-	-	-	-
MODERATE							
	Root						
	15G banded......	1(2)	5(5)	7(10)	2(6)	2(3)	2(4)
	15G in-furrow.....	0(1)	0(1)	1(1)	0(1)	1(2)	2(3)
	4E banded.......	-	0(1)	-	-	-	-
	Lodging						
	15G banded......	6(6)	-	3(3)	3(3)	-	1(1)
	15G in-furrow.....	0(1)	-	1(1)	-	-	-
	4E banded.......	-	-	-	-	-	-
	Yield						
	15G banded......	1(1)	1(1)	-	-	-	-
	15G in-furrow.....	-	-	-	-	-	-
	4E banded.......	-	1(1)	-	-	-	-
LOW							
	Root						
	15G banded......	2(2)	6(6)	9(9)	18(22)	11(12)	7(7)
	15G in-furrow.....	1(1)	1(1)	4(4)	2(3)	5(5)	2(2)
	4E banded.......	-	2(2)	-	-	1(1)	-
	Lodging						
	15G banded......	-	-	-	0(1)	1(1)	3(3)
	15G in-furrow.....	-	-	-	-	-	-
	4E banded.......	-	-	-	-	-	-
	Yield						
	15G banded......	0(1)	0(2)	0(3)	0(2)	-	0(2)
	15G in-furrow.....	-	-	0(2)	-	-	0(2)
	4E banded.......	-	-	-	-	-	-

[a]High (> 5), moderate (>4 - <5), and low (>3 - <4)
[b]To qualify for acceptable root protection, treated plant roots must have rated <3. To qualify for acceptable lodging protection, lodging must have been reduced by >80% over untreated plots. To qualify for yield protection, Lorsban-treated plots must have yielded significantly more grain than the untreated plots.

chlorpyrifos prevented serious lodging. There were significantly greater yields in chlorpyrifos-treated plots (8 of 10 trials) in trials that had moderate-to-heavy corn rootworm pressure. There were no significant differences in yield between chlorpyrifos-treated plots and untreated checks (0 of 14) in the 14 trials with "low" corn rootworm pressure. There were no significant differences in yield between chlorpyrifos-treated plots and untreated checks (0 of 14) in the 14 trials with "low" corn rootworm pressure.

Sutter et al. (1989) suggested that root-damage rating values have little bearing on how an insecticide affects the pest population or protects yield loss. Researchers found in a 4-year study that plots infested with known numbers of western corn rootworm eggs had similar levels of feeding damage at each of the pest population densities. However, these researchers found that root-damage ratings in plots that were infested with the same pest densities, when treated with granular formulations of insecticides at planting time, were highly variable from year to year. These scientists attributed most of the differences in insecticide performance to edaphic and environmental conditions. The data in Table 14 suggest that "performance" measured solely by root-damage ratings was variable from year to year.

Sutter et al. (1990) recorded consistent percentage yield loss attributed to damage by western corn rootworm larval feeding in untreated plots. These authors also found that the level of protection against yield loss afforded by granular formulations of the seven insecticides registered at the time of the study did not differ significantly among insecticides. Yields of treated and untreated plots differed only when plots were heavily infested with western corn rootworm eggs (root-damage ratings in untreated plots were greater than 5). When yields of uninfested, untreated plots were compared with yields of uninfested treated plots, significantly lower yields occurred in plots treated with some of the granular formulations, including chlorpyrifos.

Sutter et al. (1991) also examined how planting-time applications of insecticides affected rootworm survival to adulthood, rate of pest development, and fecundity of survivors. Survival of rootworms reduced by insecticides was approximately 45 percent, and chemicals that were more water soluble (e.g., carbofuran and ethoprop) reduced survival more than less water-soluble chemicals (e.g., chlorpyrifos and fonofos). Survival in untreated plots, and plots treated with chlorpyrifos 15G, did not differ significantly in 2 of the 3 years during the study. When precipitation was above normal during the larval feeding period, rate of survival in chlorpyrifos-treated plots was significantly lower than in untreated plots. However, rate of survival in plots treated with chlorpyrifos was significantly higher than in plots treated with six other chemicals. Fecundity of western corn rootworms surviving in plots treated with chlorpyrifos, terbufos, carbofuran, and isofenphos was significantly higher than in female survivors from untreated plots and plots treated with fonofos, phorate, and ethoprop.

In a 3-year study in Illinois, Gray et al. (1992) reported that planting-time applications of terbufos, chlorpyrifos, and carbofuran had highly variable effects on corn rootworm adult emergence. In one year of their study, the number of beetles that emerged was significantly lower in plots treated with these insecticides than in untreated plots. In another year, there were no significant differences in the numbers of beetles that emerged from treated and untreated plots. During the third year, the numbers of beetles where emergence was significantly greater was in treated rather than in the untreated plots. Gray et al. suggested that growers who use planting-time soil insecticides to protect corn roots are not actually managing corn rootworm populations; in some years, the long-term severity of infestations may be exacerbated.

European corn borer—The primary criterion used to evaluate insecticide performance against European corn borer is to note either the number of larvae or the incidence of tunneling in the treated areas and compare these data to the results from an untreated check plot. Few evaluations report the effects of insecticide treatments on yields.

Twenty independent evaluations of insecticides for control of European corn borers were reported in "Insecticide and Acaricide Tests" between 1989 and 1991. The results of these tests provide some insight into the relative efficacy of chlorpyrifos compared with the efficacy of other insecticides used for European corn borer control. In 18 of the 20 reports, populations of European corn borer in plots treated with chlorpyrifos were significantly lower than populations in untreated plots. In 14 of these tests, populations of European corn borer in chlorpyrifos-treated plots did not differ significantly from populations in plots treated with the insecticide that had the fewest European corn borers after treatment. Yield data were provided for only 4 of the 20 tests. Only one of these tests revealed that yield was greater in chlorpyrifos-treated plots than in untreated plots. In all four tests, however, yields from chlorpyrifos-treated plots were statistically equal to yields from plots treated with the other insecticides.

The average percentage of control provided by chlorpyrifos in 10 of the 20 tests was 70.8 (range 53.8 to 85.6), while the average percentage of control provided by the "best performing" alternative insecticide was 90.4 (range 82.4 to 97.3).

Black cutworm—The primary criterion used to evaluate insecticide performance for cutworm control is to compare the plant stand count or number of cut plants in the treated plots to those in the untreated check. Infrequently, these evaluations report on yield. There were 10 independent evaluations of insecticide efficacy on black cutworm in "Insecticide and Acaricide Tests" between 1988 and 1991. Nine of the ten studies evaluated chlorpyrifos 15G applied at planting, and one of these studies evaluated chlorpyrifos 15G applied at preplanting. Three of the ten evaluations included chlorpyrifos 4E applied as a rescue treatment during postplanting. All 10 of the experiments reported that chlorpyrifos significantly reduced cutting as compared to the untreated check. Only two studies listed an insecticide treatment that showed significantly more uncut plants than chlorpyrifos; the remaining studies showed chlorpyrifos as efficacious as other insecticides. All studies, however, had damaged plants in the chlorpyrifos-treated plots. Rescue treatments performed well in controlling black cutworm larvae, and showed a more consistent and higher percent protection of plant stand than did the planting-time treatments of chlorpyrifos. The comparative performance values used in this study were provided by David Brassard, USEPA/OPP/BEAO and are based upon a cumulative analysis of recent literature on cutworm control.

Nonchemical Alternatives

Entomologists in most Corn Belt States recommended crop rotation as the most effective nonchemical management strategy for controlling the corn rootworm complex. An exception was reported by Biggar (1932), who concluded that alternate-year rotation of corn with a nonhost crop sometimes failed to control the northern corn rootworm. A plausible explanation for northern corn rootworm damage in first-year corn was advanced by Krysan et al. (1986). They found in one study that 40 percent of the northern corn rootworm eggs were capable of overwintering in the soil for two winters before hatching, and that this trait was higher in the northern corn rootworm populations from areas where crop rotation was practiced. Thus, crop rotation for managing this pest may become ineffective whenever corn and a nonhost crop are grown in alternate years in a consistent pattern (Sutter and Lance, 1991). At the present time no biological control agents are available or registered for controlling or managing corn rootworm populations.

Biological insecticides are available for control of the European corn borer. These insecticides contain the bacteria *Bacillus thuringiensis* Berliner. These insecticides are efficacious on European corn borers that feed on corn, but have not proven as effective for control of the second-generation European corn borer. At the present time no biological control agents are available for controlling the black cutworm.

Pesticide Resistance

The cyclodiene insecticides were introduced for controlling corn rootworm more than 4 decades ago, but proved to be effective for approximately only 2 decades. The first report of inconsistent control was noted by Weekman (1961); evidence for resistance of rootworms to cyclodienes was indicated by Ball and Weekman (1962). Several years later, Hamilton (1965) reported high levels of cyclodiene resistance in the populations of western corn rootworm and in isolated populations of the northern corn rootworm. These chemicals remained in the soil for years after application, and selection for cyclodiene resistance in rootworms continued. When Krysan and Sutter (1986) compared LD_{50} responses of northern corn rootworm beetles collected from the general area reported by Hamilton (1965), these authors found that northern corn rootworm populations reported to be resistant to aldrin 2 decades earlier were still resistant, and populations reported to be susceptible were still susceptible. Krysan and Sutter (1986) also analyzed soil taken from fields where resistant northern corn rootworms were found. These authors detected residues of dieldrin in the soil that were sufficient to induce mortality at a level approximately equal to the LC_{50} of a susceptible population of the northern corn rootworm. In contrast, most carbamate and organophosphate insecticides currently applied at planting time dissipate by or before the end of the growing season. Furthermore, most of these insecticides do not necessarily control corn rootworm larval populations; instead, these chemicals protect root systems from injury (Bergman, 1987). Low selection pressure from insecticides, in conjunction with extensive movement of beetles between fields, will probably not create populations of corn rootworm that are resistant to insecticides currently registered for control of these pests (Sutter et al., 1991).

There are no reported cases of resistance of European corn borer or black cutworm to chlorpyrifos or any other available registered insecticide.

Impact on Beneficial Insects

The chlorpyrifos 4E label states that "this product is highly toxic to bees exposed to direct treatment or residues on blooming crops or weeds. Avoid use when bees are actively foraging." Chlorpyrifos 15G does not have a bee warning on the label. Lunden et al. (1986) made evening applications (0.50, 0.75, and 1.00 lb a.i. per acre) of chlorpyrifos 4E using center pivot irrigation to a field of corn that was shedding pollen. The lowest rate had minimal effect on bee mortality, but reduced the number of bees foraging for pollen by 95 percent. These authors found a fourfold increase in bee mortality when the highest rate of chlorpyrifos was applied.

From 1987 to 1991, volumes of "Insecticide and Acaricide Tests" contained no reports of chlorpyrifos affecting other beneficial insects when used in corn production. In a 3-year study in Ohio, Reed et al. (1992) showed no significant differences in mortality of adult carabid beetles, Carabidae, when comparing untreated plots and plots treated with chlorpyrifos.

Integrated Pest Management

Corn rootworms—Implementation of Integrated Pest Management programs, which includes monitoring for corn rootworm adults and the use of soil insecticides for protection from root feeding by corn rootworm larvae, is discussed in detail in "The Biologic and Economic Assessment of Phorate and Terbufos," USDA-ES Technical Bulletin No. 1785. Field scouting for pests is an integral component of IPM programs; however, scouting has not been widely implemented in field corn production. In the high-return production systems of sweet corn, seed corn, and popcorn, growers often invest in IPM and crop consultant services. In field corn production, insecticide use would decrease and economic returns might increase if more growers would implement IPM practices.

European corn borer—Because of the potential damaging impact of this insect, scouting programs, where implemented, are reasonably effective in allowing the use of published economic thresholds and correct application timing (if an insecticide application is necessary). Predictive tools are not available. However, the use of blacklight and pheromone traps often denote corn borer activity. Thus, these tools can be a good indicator to initiate scouting. There are, however, large differences in IPM implementation programs and producer adoption when comparing different areas of the country.

Black cutworm —Growers use either planting-time preventive applications or postemergence rescue applications of insecticides to control black cutworm larvae. Of these two chemical strategies, only the postemergence rescue applications fit with IPM principles. The incidence of black cutworm is sporadic in most areas of the country; therefore, the vast majority of planting-time applications for cutworm control are not necessary. When infestations of black cutworm are severe, fields treated with planting time applications often require an additional rescue application of an insecticide to achieve satisfactory control. Properly applied rescue applications are more consistently effective than planting-time applications. However, rescue treatments have a significant labor requirement and necessitate a high level of management to properly scout, recognize damage, and implement the proper control measures. This can be accomplished under consultant advisement. However, the majority of growers do not take the time and/or would require additional training to properly use the rescue treatment option. Consequently, the planting-time application option continues to be used in many areas of the country.

FUTURE PEST MANAGEMENT OPTIONS

Corn rootworm—Recent advances in the knowledge of chemical ecology of corn rootworm beetles have opened new avenues for the development and deployment of effective management strategies for these pests (Lance and Sutter, 1990; Sutter and Lance, 1991). Specifically, attempts have been made to develop semiochemical-based technologies for monitoring, and, when necessary, suppressing populations of corn rootworm beetles (Sutter and Lance, 1991; Levine et al. 1990; Weissling and Meinke, 1991). Corn rootworm management with semiochemical-based technology has been evaluated in regional projects in five Corn Belt States from 1989 to 1991. Although results from these large-scale field evaluations have not always been consistent, most researchers have concluded that this approach, which uses 95 to 98 percent less a.i. of insecticide per acre, can reduce populations of corn rootworm adults to levels that will prevent severe infestations of larvae during the next growing season, while having a minimal impact on nontarget organisms in corn production fields. Longer lasting baits, improvements in application technologies and in management skills of producers, and new Federal registrations are needed before wide-scale adoption by growers can occur.

European corn borer—Numerous biological agents attack the European corn borer during its life cycle. Insecticides containing *Bacillus thuringiensis* are recommended by most States in the Corn Belt as a viable control option. These insecticides can be applied with center pivot irrigation and are an attractive alternative control strategy. Other biological agents that are being tested experimentally for management of European corn borer include *Trichogramma* spp., which parasitize European corn borer eggs; parasitic protozoans, which weaken borers and reduce winter survival and moth oviposition rates; and *Beauveria bassiana*, a widespread fungus, which often kills high percentages of overwintering borers.

Black cutworm—Although some research is on-going to search for biologicals to manage cutworms, there are no commercial applications to date.

SUMMARY

Insecticides are used extensively on the 69 million acres of corn grown in the United States. Seventy-five percent of these acres are located in the 10 Midwestern Corn Belt States. In field corn alone, approximately 28 million acres are treated with granular insecticides at planting or occasionally at cultivation time. The major target in the 10 Corn Belt States is the corn rootworm complex, with a generally lesser emphasis on cutworms, wireworms, white grub, and other soil insects. An example of an exception is Missouri, where the primary target insect is usually the black cutworm. Outside the Midwestern Corn Belt region, significant acreages, although fewer than in the Corn Belt, are being treated for other soil and foliar insects of importance—for example, billbugs, cutworms, wireworms, white grubs (to name a few)—with less or no emphasis on corn rootworm larvae. An additional 6.3 million acres of field corn are treated with liquid formulations of insecticides. The primary target is the European corn borer, with lesser control efforts aimed at black cutworm and an array of other insects, including corn earworm, armyworms, cutworms, billbugs, chinch bug, and others. Based on responses to questionnaires sent to 38 States, the following overview is offered in an attempt to capture the intent and theme of the responses.

In the Corn Belt States where the chief concern is the three primary insect pests (corn rootworms, European corn borer, and black cutworm), there would likely be a negligible impact on grain yield if chlorpyrifos 15G and 4E were removed from the market. There will, however, be a major shift in product selection, since responders reported significant usage of chlorpyrifos in the marketplace. For root protection from corn rootworm larvae in continuous corn, viable alternative insecticides are available. There are also viable alternative insecticides for European corn borer and black cutworm management. The negligible impact is premised, however, on the continued availability of alternative insecticides and a continued increase in adopting and implementing IPM practices, particularly field scouting and the use of economic thresholds.

Of some uncertainty is the impact on grain yield in those regions where soil insect pests other than corn rootworm are of greater importance. The major insects in these areas include varying populations of the primary insect pests, plus a number of the secondary insects—for example, armyworms, wireworms, billbugs, flea beetle, white grub, southwestern corn borer, and chinch bug. Much of this uncertainty comes from the sporadic and unpredictable incidence of these pests and the paucity of information on their impact on grain yield and on the impact of chlorpyrifos for protecting the grain yield in the presence of these pests. The main concern is the limited number of, or lack of, chemical alternatives that growers can use in the traditional, preventive planting-time insecticide application strategy against this insect complex.

Documentation seems to indicate that the highly variable edaphic and climatic factors in these regions often differentially affect soil insecticide efficacy. Therefore, chlorpyrifos may be the only effective soil insecticide in some situations, though not in others. The situation is complex, and most entomologists view the soil insecticides as an array of management tools, perhaps grouped for certain field conditions, but *not* as individual insecticides. The elimination of one insecticide alters and limits choices, and in selected situations will, at times, negatively impact corn production. These areas of corn production outside the Corn Belt States represent less than 25 percent of the corn acreage; nonetheless, production in these areas is of regional importance.

Several viable insecticide alternatives are available for post-planting applications. For some pests, however, (wireworms and white grub, for example) postplanting application is not a feasible option. Although the major use of soil insecticides on corn is directed toward "controlling" corn rootworm larvae, there is increasing evidence that a substantial amount of the corn acreage treated with soil insecticides at planting does not harbor economic infestations of rootworm larvae.

While currently efficacious alternative chemicals are available for all three primary insect pests, these alternatives have two major limitations. First, there are no alternatives to chlorpyrifos 4E that can be applied through center pivot irrigation systems for corn rootworm larvae control. This management option is more compatible with IPM principles than the "preventive" planting-time application of soil insecticides. Second, tefluthrin is the only alternative for planting-time applications that appears to offer as broad a spectrum of insecticidal activity as chlorpyrifos in protecting plant stands from cutworm and other soil insect damage, including rootworm larvae damage. However, the at planting-time insecticide application strategy is a preventive treatment applied prior to knowing if pest populations necessitate treatment.

Chlorpyrifos 15G and 4E carry a "caution" label statement, generally indicating a lower risk to the handler, and are the only soil insecticides recommended for corn rootworm control. Their primary use is as a General Use pesticide.

Recent documentation indicates that the adverse interaction among certain applications of terbufos and two sulfonyl urea-based herbicides (nicosulfuron [Accent] and primisulfuron [Beacon]) is significant where these two postemergence herbicides are used in corn production. This interaction does not seem to be significant with soil-applied formulations of chlorpyrifos or the other alternative soil insecticides registered for control of corn rootworm larvae in corn. Therefore, in areas where terbufos cannot be used as an alternative insecticide, and when granular formulations of carbofuran are no longer available, availability of alternative soil insecticides for control of corn rootworm larvae would be limited.

Withdrawal of chlorpyrifos 15G and 4E would leave producers with one less insecticide that can be used in such a resistance-management chemical rotation. Some State scientists recommend rotating insecticides to extend the useful life of each insecticide.

Several respondents indicated that chlorpyrifos provided the broadest based control for an array of secondary soil pests. However, the overall rating of performance in controlling secondary pests was mixed, and the use of broad-based insecticides may not always be environmentally sound.

Because of its low solubility in water and limited movement within the soil profile, chlorpyrifos is more acceptable than some of the other soil insecticides from the water quality standpoint. This inherent characteristic is desirable for reducing the potential contamination of groundwater and surface water.

Corn growers have options that do not rely solely on chemical insecticides for managing the primary insect pests; for example, crop rotation, biological agents, and cultural practices. New technologies for pest monitoring, population suppression, and pest management that require greatly reduced rates of insecticide, and are less environmentally intrusive, are being developed. Until new regulations cause significant changes in pesticide use, however, soil insecticides applied at planting and occasionally at cultivation time will continue to be a common management practice in continuous corn production.

Assuming that this major usage of soil insecticides will continue (particularly for control of rootworm larvae), chlorpyrifos will continue to rank favorably compared to its alternatives for several reasons, including the following: (a) it is a General Use insecticide and carries a category III "caution" statement on the label, indicating a lower risk, (b) it has a low solubility in water and is less mobile in the soil environment, thus significantly reducing the risk of leaching, (c) it has a broad spectrum of activity against soil insects, and (d) it is available in both granular and liquid formulations.

Chlorpyrifos Use on Cotton

Paul B. Baker and Robert B. Head

INTRODUCTION

Cotton, *Gossypium hirsutus* L., is an important cash crop in the United States in terms of both domestic consumption and foreign trade. In 1988, cotton was the fifth most valuable field crop (production of $4.8 billion) after corn ($13 billion), hay ($10.6 billion), soybeans ($7.8 billion), and wheat ($6.6 billion). An average of approximately 12 million acres of cotton was harvested in 1988, or about 4 percent of the total harvested U.S. cropland devoted to major field crops. Production for 1987 to 1989 in the 15 Southern and Western States is represented in Table 15, which shows that more than 60 percent of the total U.S. cotton production was harvested in California, Mississippi, and Texas.

Chlorpyrifos is labeled for use on cotton for control of cotton fleahopper; plant bugs; cotton aphid; beet, fall, and yellow-striped armyworms; thrips; spider mites; bollworm; budworm; boll weevil; cutworms; pink bollworm; grasshoppers; and saltmarsh caterpillar. Chlorpyrifos is applied to the foliage at a rate of 0.375 to 1.0 lb a.i. per acre. This pesticide can be applied by ground or aerial application equipment, or through irrigation systems. Chlorpyrifos can also be tank-mixed with emulsifiable concentrate formulations of other organophosphates or pyrethroids.

Chemical alternatives to chlorpyrifos include various organophosphates (e.g., acephate, methyl parathion, and methamidophos) and pyrethroids (e.g., bifenthrin and cyfluthrin). These alternative products are used more frequently than chlorpyrifos.

Table 15. United States Cotton Production, 1988-89

State	Area Harvested *(acres)*	Average Yield *(lb/acre)*	Total Production *(480 lb bales)*
Upland cotton			
Alabama	349,000	536	389,000
Arizona	292,000	1,309	791,000
Arkansas	607,000	738	932,000
California	1,172,000	1,166	2,821,000
Florida	28,000	622	36,000
Georgia	275,000	620	353,000
Louisiana	622,000	721	933,000
Mississippi	1,073,000	766	1,710,000
Missouri	217,000	674	302,000
New Mexico	62,000	699	90,000
North Carolina	110,000	540	124,000
Oklahoma	383,000	342	276,000
South Carolina	126,000	511	134,000
Tennessee	472,000	578	564,000
Texas	4,467,000	451	4,250,000
Other	3,500	497	3,600
Total	10,258,500	642	13,708,600
Pima Cotton			
Arizona	154,000	974	303,000
California	7,000	995	14,000
New Mexico	21,000	649	28,000
Texas	49,000	788	82,000
Total	231,000	903	427,000
Total (all cotton)	10,489,500	648	14,135,600

Source: Annual Crop Summary, NASS, USDA, January 1990.

PEST INFESTATION AND DAMAGE

Certain insect pests are confined to specific production regions (e.g., pink bollworm in the Western States) while other pests are endemic across the Cotton Belt (e.g., thrips and plant bugs). Different insects infest cotton at each stage of development. As discussed in the NAPIAP aldicarb assessment, a brief overview of each pest is presented below (USDA, 1991).

Cotton fleahopper—The cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter), is generally distributed across the Cotton Belt, causing damage in various areas in Texas. This pest has the potential to be more injurious than the boll weevil. The cotton fleahopper inflicts most of its damage when the squares are small, and in the early-fruiting stage of the cotton plant.

Lygus bugs—Lygus bugs (Miridae), common throughout the Western United States, are particularly important in the San Joaquin Valley and in New Mexico. Lygus bugs have several generations each year, but usually not more than three generations develop on cotton per year. Alfalfa is a preferred host that harbors this insect all year; this crop is usually the main source of infestation. When alfalfa is cut, lygus bugs fly to nearby hosts, including cotton. In addition, continuous lygus bug infestations can result due to migration from native crops and weed hosts as plants mature. *Lygus hesperus* Knight is the predominant species in the Western States, while the tarnished plant bug *L. lineolaris* (Palisot de Beauvois) is more prevalent in the South.

Damage from lygus bugs occurs mostly to the squares less than 1/5 inch long. These insects pierce the squares and consume anthers and other tissue, causing the square to shrivel, turn brown, and drop from the plant. The 1987 NAPIAP aldicarb questionnaire indicated that individual field loss can exceed 70 percent.

Cotton aphid—The cotton aphid, *Aphis gossypii* Glover, can be found wherever cotton is grown. In the Southeast, severe infestations of this pest stunt young plants, and yield losses can be expected in the absence of controls. In western parts of the country, the injury to cotton incurred from these pests is rarely of economic importance. However, when infestations occur during main fruiting periods (early bloom to full bloom), the older leaves turn yellow and are shed, causing premature opening of bolls and incomplete development of fiber. Researchers in the Southeast have documented that light infestations of aphids early (with moderate to heavy populations during peak fruit set) can reduce yields significantly. Outbreaks of the cotton aphid have been attributed to this pest's resistance to carbamate, organophosphate, and pyrethroid insecticides; destruction of natural enemies; and host plant environmental interaction (Kerns and Gaylor, 1992).

Beet and fall armyworms—In the early part of the season, beet armyworm, *Spodoptera exigua* (Hubner) populations can develop on seedling cotton. The beet armyworm starts feeding from near its egg clusters. Afterwards, this pest gradually disperses away from the cluster area as the pest grows older. Older larvae chew irregular pieces from the leaves, and also feed on squares, flowers, and small bolls. The beet armyworm's injury to leaves is important only in rare cases when large numbers of larvae attack small plants. The fall armyworm, *S. frugiperda* (J.E. Smith), is a sporadic pest of cotton, usually in the mid-season. However, this pest's preferred hosts are sorghum and corn. Damage is similar to that of the bollworm and tobacco budworm.

Spider mite—A number of species of this pest group attack cotton, often causing serious damage. The most important pests are: Carmine spider mite, *Tetranychus cinnabarinus* (Boisduval); desert spider mite, *T. desertorum* Banks; *T. lobosus* Boudreaux; Pacific spider mite, *T. pacificus* McGregor; Schoene spider mite, *T. schoenei* McGregor; strawberry spider mite, *T. turkestani* Ugarov & Nikolski; tumid spider mite, *T. tumidus* Banks; twospotted spider mite, *T. urticae* Koch; and *T. ludeni* Zacker.

Spider mites are present throughout the year on perennial hosts such as alfalfa. These pests build up on weeds and annual crops as these plants are growing. Factors regulating mite populations are temperature, the condition of the host plants, and activity of predators. As nighttime temperatures increase, pest populations can increase unless predators are abundant. In some cases, suppression of boll weevil, bollworm, or tobacco budworm may also suppress spider mite populations.

Boll weevil—The boll weevil, *Anthonomus grandis grandis* Boheman, is a major cotton pest in Mexico and the Southern United States. The adults and larvae feed mainly on squares, but also attack the bolls. Squares punctured by adults usually flare and drop. Injured squares can be identified by the punctures and yellow frays usually found on the outside. Once a field is infested with boll weevils, repeated insecticide applications are needed for control. The key management strategy is to reduce overwintering populations by early harvest and prompt shredding and plowdown.

Cutworms—Cutworms, Noctuidae, hide in the soil during the day, emerging at night to feed on seedling plants. On cotton, cutworms either feed on the plants at ground level or consume the entire seedling. Economic infestations of cutworm in cotton are rare, but usually follow rotation from crops such as alfalfa when large amounts of plant debris are plowed under.

Bollworm/Budworm—The bollworm, *Helicoverpa zea* (Boddie), and the tobacco budworm, *Helicoverpa virescens* (Fabricius), attack cotton throughout the Cotton Belt. Bollworm and budworm can cause significant losses by feeding on squares and green bolls. Older larvae do most of the damage, but control measures should be aimed at small larvae. Both of these insect species have substantial tolerance or resistance to common insecticides. Treatment thresholds are based on counts of small larvae in the tops of plants.

Thrips—Thrips are the primary pests targeted with at-planting applications. Thrips are most damaging during the early stages of cotton development (Head, 1990). In the western region, thrips are present all season in most cotton fields. This pest is usually noticed only in cool spring weather, when feeding causes leaves of slow-growing seedlings to become wrinkled and distorted. When thrips feed on seedling cotton, the result is stunting, delayed maturity, and reduced yields. One study in Arkansas indicated that thrips reduced cotton stands by 19 percent, reduced leaf area by 88 percent, and delayed fruiting by 2 weeks (Carter et al., 1989).

The emergence of thrips in the high plains of the Midwest cotton region has the potential to significantly reduce leaf surface area, specifically at the fourth and fifth true leaf stage.

These reductions potentially delay square initiation and reduce final yield (Leser, 1986).

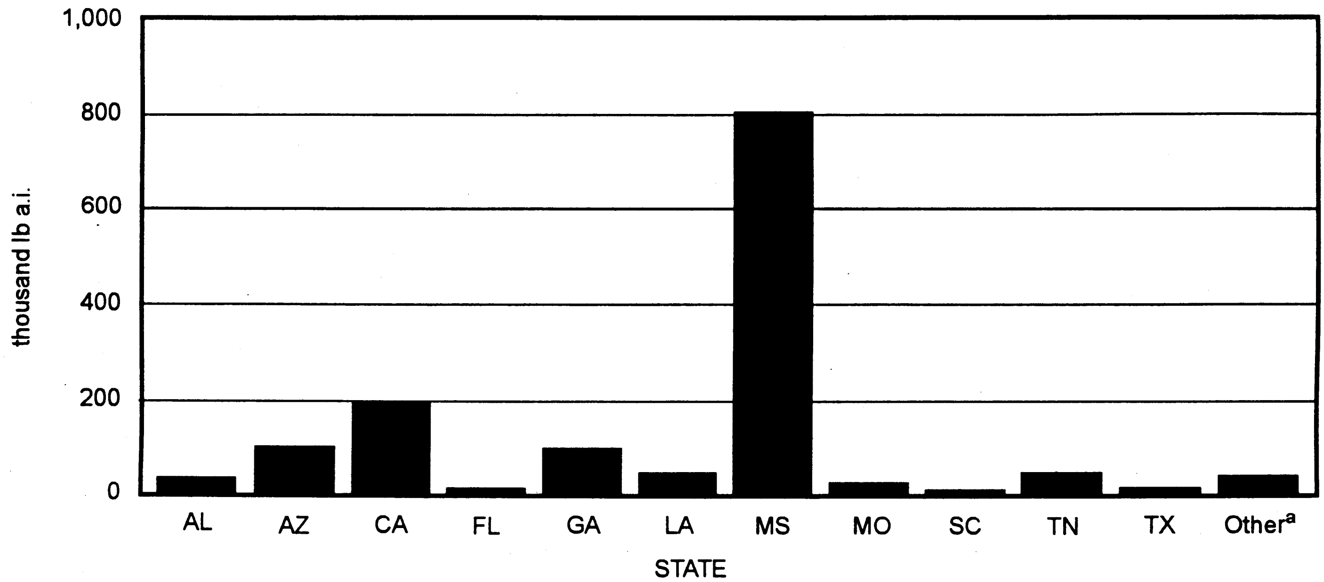
PEST MANAGEMENT

Current Chemical Usage

Survey returns from States indicate that chlorpyrifos was used on 1.4 million acres (13 percent) of harvested cotton, requiring the application of 1.4 million lb a.i. and costing $12.8 million. The amount of chlorpyrifos used in reported States is presented in Figure 8. The percentage of acreage treated with chlorpyrifos ranged from 1 percent in North Carolina and Texas to 50 percent in Arizona. The West (Arizona and California) and Delta (Missouri, Arkansas, Tennessee, Mississippi, and Louisiana) regions used chlorpyrifos on approximately 10 percent of the acreage. Chlorpyrifos-treated acreage in the Southeast (Alabama, Georgia, South Carolina, and North Carolina) and Southern Plains States (New Mexico, Oklahoma, and Texas) in most cases amounted to less than 5 percent. Comments received indicate that chlorpyrifos is excellent against armyworm and cutworm complexes. However, these pests are not economic problems every year.

The pesticide use survey addressed the comparative performance rating of each alternative treatment (chemical and nonchemical) versus chlorpyrifos. The estimated change (±) in yield and quality if chlorpyrifos were not available ranged from 1 to 3 percent loss. States reporting expected losses were Arizona (-3 percent), Louisiana (-1 percent), Oklahoma (-3 percent), and South Carolina (-3 percent). Arizona reported a unique situation related to a pest complex (involv-

Figure 8. Chlorpyrifos 4E Use on Cotton, 1987-89 Average
[Total = 1,432,531 lb a.i.]



[a]Other = NC,OK

ing a particular formulation of chlorpyrifos developed specifically for low humidities of the desert) that can be successfully used as a pest management strategy in controlling pink bollworm and beet armyworm.

Chemical Alternatives to Chlorpyrifos

Available alternative chemicals include acephate, dicrotophos, bifenthrin, dimethoate, methomyl, profenofos, sulprofos, and thiodicarb. Chlorpyrifos is the only insecticide that can be applied by chemigation. The cost of chlorpyrifos averaged $7.40 per acre, which is in the middle of the range, with the lowest at $2.00 for dimethoate to the highest for bifenthrin at $13.18 per acre. As for the cost of application, chlorpyrifos is in the middle range for both aerial and ground applications, with $3.40 and $2.50 per application per acre, respectively.

Foliar applications of most alternative insecticides to control pests such as thrips have a negative impact on the predators and parasites of other cotton pests, and thus may contribute to pest outbreaks. Repeated applications of foliar insecticides may also intensify selection for resistance in both target and nontarget pests.

Comparative Performance

The advantage chlorpyrifos provides to an IPM system is its effectiveness in the early season control of pink bollworm, tobacco budworm, and beet armyworm. Many of the alternatives do not provide this same flexibility for control of these pests. Although chlorpyrifos is generally not reported to be a preferred material, it has a role in the IPM strategies in cotton.

Nonchemical Alternatives

Cotton is better able to tolerate thrips infestation when it is grown in an environment that promotes vigorous growth. Less than optimal environmental conditions, particularly air temperatures below 60 °F (which are common during May in the northern portions of the Southeast and MidSouth), increase the importance of thrips management. Early season growth of cotton is stimulated when the seedbed is well prepared and high quality seed is planted. A good disease management program is also important to ensure vigorous plant growth.

Rotation of cotton with other crops such as soybeans, corn, grains, sorghum, and legumes improves plant health and vigor and therefore may increase the plant's ability to withstand infestations of insect pests. However, rotation is a viable strategy only when the producer has an excess of quality soils. In most cases, the quality of soils is limited, and cotton is grown continuously in the same fields for decades.

Pesticide Resistance

The use of chlorpyrifos, which is an organophosphate, increases the potential for pest resistance to organophosphate insecticides. However, the use of chlorpyrifos also reduces the potential for pest resistance to pyrethroid and carbamate insecticides. An important example is in the "resistance management program" in Mississippi where chlorpyrifos is exclusively recommended for early season cutworm control, and pyrethroid insecticide use is reserved for tobacco budworm control.

Multiple resistance has become increasingly common among key pests such as *Helicoverpa* spp., which have developed resistance to several classes of insecticides, including pyrethroids (Osman et al., 1992).

Impact on Beneficial Organisms

Chlorpyrifos has an impact on beneficial organisms, as do other currently registered broad-spectrum insecticidal alternatives.

Integrated Pest Management

Chlorpyrifos is a product that is used in cotton IPM systems. Chlorpyrifos can be used in early season cotton to reduce initial generations of pink bollworm. This chemical also provides protection in secondary outbreaks of beet armyworm. The greatest advantage of using chlorpyrifos is that it provides early season control to avoid additional sprayings in mid- to late-season cotton. Before insecticides are applied, monitoring of various insect pests must demonstrate that the populations have exceeded treatment thresholds, since biological control agents will be significantly affected and pest resurgence can occur. For example, treatment for lygus bugs may cause outbreaks of secondary pests, especially spider mites.

FUTURE PEST MANAGEMENT OPTIONS

Cotton growers continue to show a growing interest in adopting nonchemical control measures; however, few of these nonchemical measures are currently available. Insecticides continue to be the main option available for pest management. As for the development of new chemicals, the outlook is very poor, with only three new insecticides registered in 1991.

SUMMARY

Chlorpyrifos is applied to approximately 1.4 million acres (13 percent) of cotton produced in the United States. All reporting States indicated chlorpyrifos use on cotton. Of the available insecticides, chlorpyrifos was not a primary choice. However, in certain production areas such as Arizona, or against armyworm and cutworm complexes, this chemical is a preferred material. The cancellation of chlorpyrifos will leave some States fewer available alternatives for IPM.

Chlorpyrifos Use on Grass Seed Crops

John Rinehold and Jeffrey J. Jenkins

INTRODUCTION

The Pesticide Label Information Retrieval System (PLIRS) contains label information for pesticides registered in the Pacific Northwest (Washington, Oregon, and Idaho). Table 16 is the PLIRS list of insecticides registered on grass and on grass seed crops as of May 1992. This list contains the insecticides that could serve as chemical alternatives for certain usages if chlorpyrifos were discontinued.

PEST INFESTATION AND DAMAGE

Cutworms—Several species of cutworms affect grass and grass seed crops in the Pacific Northwest. Glassy cutworm, *Apamea devastator* (Brace), is a pest that attacks bentgrass, fine fescue, and Kentucky bluegrass in the Willamette Valley of western Oregon. The cutworm *Protagrotis obscura* attacks grass and grass seed crops in eastern Oregon, Washington, and Idaho. *Agroperina* spp. infests bluegrass in northeastern Oregon. Although quantitative measurements of yield loss due to cutworms have not been made, there is evidence that cutworms have destroyed large portions of grass seed fields in Oregon (J.A. Kamm, 1991, personal communication). Grass seed fields are perennial, so stand loss affects more than the current year's crop; in addition to the loss of the year's production, an additional establishment year is needed to produce a new stand.

Table 16. Insecticides registered on grass and grass seed crops for cutworm, billbug, and aphid control; rates applied, and number of labels available, derived from PLIRS and from the *Pacific Northwest Insect Control Handbook*.

Pest	Chemicals Registered	Rates Applied *(lb, unless noted)*	Labels
	Grass Seed Crops		
Cutworms....	Chlorpyrifos	1.0 lb/acre	5
	methyl parathion	0.5 - 0.75	1
	Bacillus thuringiensis	0.5 lb WP	2
	carbaryl	1.0 - 1.5	8
	lindane	1.5 - 2.0 pt	3
Billbugs......	diazinon	3 lb granules	1
	chlorpyrifos	1.0	3
	lindane	1.5 - 2.0 pt	3
	carbaryl	4.0	5
Aphids	dimethoate	0.33 - .05	2
	chlorpyrifos	0.5 - 1.0	3
	lindane	1.5 - 2.0 pt	2
	methyl parathion	0.25 - 0.5	1

There is one generation per year of the glassy cutworm and *P. obscura* in grass fields. Adults are present from May to June. Cutworm larvae can be found feeding on the roots and crowns of grasses from spring to late summer and fall. Fall cutworm damage appears in bluegrass stands as irregular brown spots on the blades that may enlarge in the spring, resulting in extensive damage.

Cutworm infestations generally occur in high spots within grass fields because these areas are the most attractive to moths for egg laying. Moths avoid low spots in fields, especially when moisture such as dew is present. Many moths tend to settle in the same area of a field; thus, cutworm problems are concentrated in localized areas within fields. During harvest, swaths are cut in fields and seed crops dry on the ground for 7 to 10 days. These swaths provide protected areas that can attract higher numbers of moths and concentrate egg-laying and cutworm feeding. Fields thus infested will have dead and damaged strips where swaths were left to dry, while uncovered areas remain relatively free of cutworms (W.W. Willard, 1991, personal communication).

Billbugs—Billbugs, *Sphenophorus* spp., attack orchardgrass grown for seed in the Willamette Valley of Oregon, and are also a turf and lawn pest. The billbug has been a problem in grass seed fields since 1965; serious feeding damage caused by its larvae often results in loss of stands and up to 50 percent reduction in seed yields (Berry, 1978). There is a high correlation between billbug larval density and fall tilling in orchardgrass (Kamm and Every, 1969). Seed yield of the subsequent year's crop may not be proportional to larval density; thus, yields in heavily infested fields are greatly reduced. In the spring, female billbugs chew holes in grass stems and deposit eggs into these cavities. Eggs hatch in 1 to 3 weeks, depending upon the temperature. After hatching, larvae feed inside the stem, then move to the soil to feed on the grass crowns and roots. The larvae cut the roots from the shoot, which results in plant death, brown areas of loose sod within fields, and subsequent stand loss. Adults feed on grass stems; however, adult damage is not as severe as that caused by the larvae. Larval damage during July and August may affect next season's crop because larval feeding weakens or destroys the crowns.

Adults disperse within fields or to adjacent fields during the spring, with egglaying occurring during May and early June. A biological component to population suppression of billbugs is *Beauveria* spp., a pathogenic fungal disease of beetles. This fungus is present in a small percentage of larvae and adults in the winter and early spring, but not during the summer.

Table 17. Three-year average for chlorpyrifos and alternative chemical treatments in Oregon, Washington, and Idaho

Chemical	Percent Fields Treated	Primary Target Pest	Impact if chlorpyrifos were not available and a substitute used		
			Region	Yield	Quality
				(percent)	
chlorpyrifos 4E	---	*Protagrotis* spp., Glassy cutworm	Idaho	-60	-20
chlorpyrifos 4E	---	*Protagrotis* spp., Glassy cutworm	Washington	---	---
chlorpyrifos 4E	15	*Protagrotis* spp., Glassy cutworm	Oregon	---	---
chlorpyrifos 4E	85	Billbug	Oregon	---	---

Source: This table is a compilation of survey information provided by Walt Willard, Jacklin Seed Co. (Post Falls, ID), and Ron Burr, Agricultural Research, Inc., Sublimity, Oregon.

PEST MANAGEMENT

Current Chemical Usage

Table 17 contains the estimated yield reduction if chlorpyrifos were not available and a substitute chemical were used in its place. The criteria for seed quality in this table are germination and purity. For foundation seed in Idaho, the market demands 98-85, which is 98 percent germination and 85 percent purity (W.W. Willard, 1991, personal correspondence). Seed certification standards differ in Oregon according to the type of certification and grass seed crop. Grass damaged by cutworms and billbugs will have more blank and underweight seeds.

Table 18. Insecticides registered on grass seed crops for cutworm, billbug, and aphid control where a feeding tolerance has been established.

Pest	Insecticides
Cutworms	methyl parathion Bacillus thuringiensis carbaryl
Billbugs	diazinon carbaryl
Aphids	dimethoate methyl parathion

Source: *1991 PNW Insect Control Handbook*

Chemical Alternatives to Chlorpyrifos

Table 16 contains a list of all of the insecticides registered for pest control in grass and grass seed crops. No registered chemical is more effective for controlling cutworms and billbugs than chlorpyrifos (R. Burr, 1991, personal communication). Grass seed screenings can be pelleted and used for livestock feed if the pesticides used during the growing season have a tolerance on livestock. Seed screenings carrying pesticide residue that do not have such livestock tolerances must be composted. Monitoring pesticide use in grass seed fields is a major undertaking for management, especially when 30 to 40 million lb of grass seed are screened each year in cleaning facilities (Willard, 1991, personal correspondence). Table 18 lists those pesticides that have a livestock feeding tolerance.

Comparative Performance

Chlorpyrifos provided 77 to 100 percent control of the *Agroperina* spp. larvae in an insecticide test conducted in 1976 (Kamm, 1980). In a 1979 trial, labeled rates of chlorpyrifos provided 61 to 69 percent control of *Agroperina* spp. Both of these tests are summarized in Table 19. In a 1980 insecticide test for grass pests, permethrin at 0.5 lb per acre reduced *Protagrotis obscura* populations by 24 percent, diazinon at 1.0 lb per acre reduced populations by 33 percent, and methomyl at 1.0 lb per acre was ineffective (Kamm, 1981). Chlorpyrifos was not used in this latter trial.

SUMMARY

Grass stands in Oregon, Idaho, and Washington will be placed in jeopardy if chlorpyrifos is not available to control cutworms and billbugs. Seed losses due to cutworms in Oregon alone would total $900,000 the first year. Many bluegrass fields in Idaho would be taken out of production. Billbugs attacking orchardgrass in Oregon would cause from $800,000 to $1,200,000 in losses annually. With the continued use of chlorpyrifos, these losses can be avoided.

Table 19. Insecticides test 1976 and 1979 for control of cutworm larvae (*Agroperina* spp.) in bluegrass, La Grande, Oregon

Chemical	lb. a.i. Per Acre	Date Applied	Date Evaluated	Number Larvae Per 8 in. Core of Sod	Percent Control
1976					
chlorpyrifos	2.0	April 13	May 7	0.6	77
chlorpyrifos	4.0	April 13	May 7	0.0	100
check	---	April 13	May 7	3.4	---
1979					
chlorpyrifos	1.0	October 11	October 23	0.9	61
check	---			2.3	
chlorpyrifos	2.0	October 11	October 23	2.8	42
check	---			4.8	
chlorpyrifos	1.0	October 11	October 23	1.2	69
check	---			3.9	
chlorpyrifos	2.0	October 11	October 23	0.2	60
check	---			0.5	

Chlorpyrifos Use on Peanut

Phillip G. Mulder, Jr.

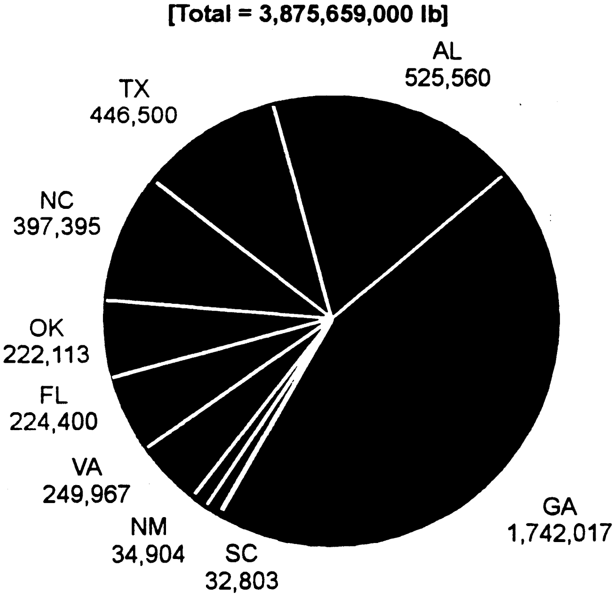
INTRODUCTION

U.S. peanut production occurs in three geographic regions: the Southeast (Georgia, Florida, and Alabama); the Southwest (Oklahoma, Texas, and New Mexico); and the Virginia-Carolina region (Virginia, North Carolina, and South Carolina). For production statistics, see Figure 9. Peanut production is centered in the Southeast. This area represents more than 1.5 million acres of peanut, with a market value of approximately $1 billion (1987 to 1989 average).

Maximum yields are obtained when peanuts are grown on sandy soils that have light to medium texture and good drainage (Pattee and Young, 1982). Peanut crops are commonly rotated with a grass crop (e.g., wheat, corn, etc.) or cotton to aid in weed, disease, and insect suppression. Irrigation of peanut is more common in the Southeast and Southwest than in the Virginia-Carolina production region. The number of days required for maturity ranges from 100 days for Spanish and Valencia peanut to 160 days for Virginia peanut.

Water, temperature, and frost are the major factors limiting peanut yields in this country. Secondary factors that limit peanut production include diseases, insects, weeds, and fertility. In irrigated peanut production, disease outbreaks are the primary pest complex affecting yields. Many peanut diseases are aggravated by conditions of high humidity. Therefore, frequent, light irrigations contribute to a favorable environment for the development and spread of disease, even if prevailing weather conditions are not excessively humid (Sholar et al., 1991).

Figure 9. Peanut Production, 1987-89 Average (1,000 lb) [Total = 3,875,659,000 lb]



Source: Crop Production, 1989 Summary, NASS, USDA

Chlorpyrifos 15G and 4E are labeled for application on peanut. Application of chlorpyrifos is for wireworm (Elateridae) suppression and is used as a preplant broadcast spray at 2 lb a.i. per acre. Chlorpyrifos 15G is labeled for at-planting preventive application, postplant preventive application, and postplant rescue treatment. Preventive applications provide control of cutworms, the lesser cornstalk borer, and the southern corn rootworm (larvae). Chlorpyrifos 15G is also labeled for suppression of wireworms and white mold (southern blight or southern stem rot). The band rescue application also provides control of lesser cornstalk borer. For usage details, see Figure 10.

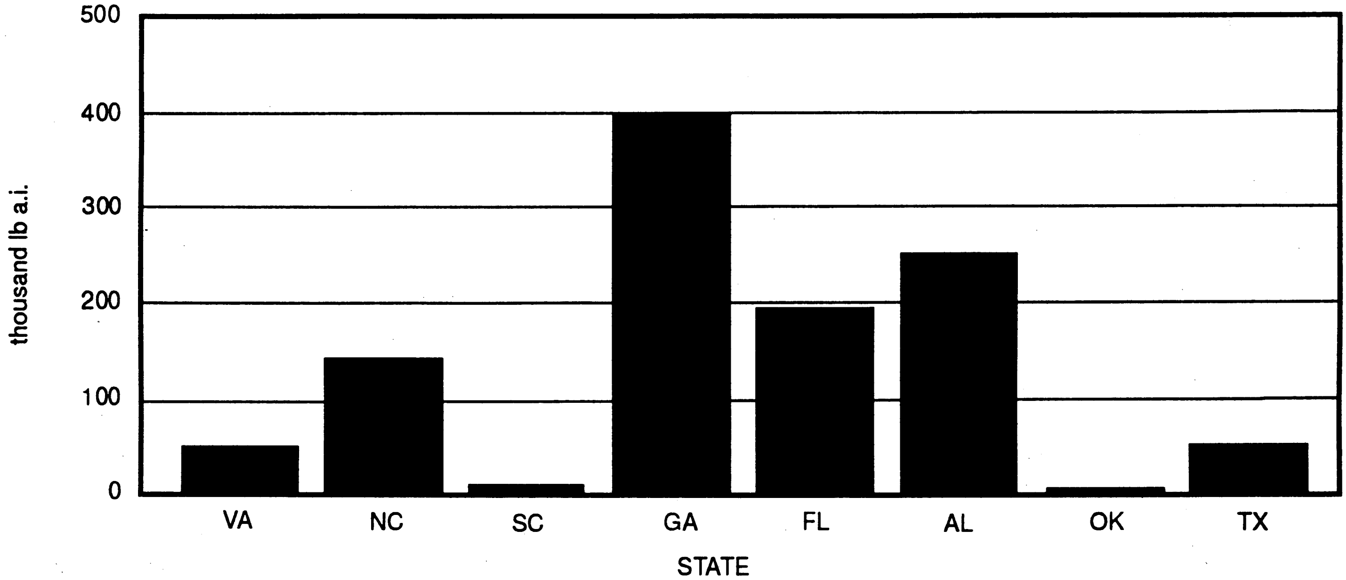
PEST INFESTATION AND DAMAGE

Primary Pests

The lesser cornstalk borer, *Elasmopalpus lignosellus* (Zeller) and southern corn rootworm larvae, *Diabrotica undecimpunctata howardi* Barber, are the major target insect pests at pegging. The lesser cornstalk borer is regarded as the major insect problem in the Southwest and Southeast United States (King et al., 1961; Mulder et al. 1990; Leuck, 1967; Walton et al., 1964). In both of these regions, damage and outbreaks of these pests are associated with hot, dry years or in dryland production areas with well-drained, sandy soils (Walton et al., 1964; Luginbill and Ainslie, 1917). Larval feeding from the lesser cornstalk borer has been described by several authors (Arthur and Arant, 1956; King et al., 1961; Leuck, 1966; Mack et al., 1988; Smith and Holloway, 1979; Berberet et al., 1986; Lynch, 1984). The larval stage is subterranean and feeds on buds, leaves, and plant stems at the ground level. Older instars may also feed on pegs (gynophores) and pods (Leuck, 1966; Lynch, 1984; Mack et al., 1988). In the Virginia-Carolina production region, the lesser cornstalk borer and granulate cutworm, *Agrotis subterranea* (Fabricius), have also shown dramatic influences on peanut yield (Brandenburg, 1990). In addition to the effects on yield from lesser cornstalk borer feeding, Bowen and Mack (1993) have recently reported a significant correlation between lesser cornstalk borer damage and *Aspergillus flavus*, or aflatoxin contamination. Insecticides used for lesser cornstalk borer control are usually applied at-pegging (R2 to R3). However, effective protection should be provided from flowering to late podfill (R1 to R7) to avoid yield losses (Mack et al., 1989).

At-pegging applications may also target southern corn rootworm larvae. During the larval stage, this small beetle is also a subterranean pest, feeding on peanut pegs and pods (Hunt and Baker, 1982). Southern corn rootworm larval infestations are generally associated with peanut grown on soils with a high clay content. These soil types are typical of peanut production areas in the Virginia-Carolina region (Campbell and Emery, 1967). The southern corn rootworm larva is rarely a problem in the Southeast or Southwest production areas.

Figure 10. Chlorpyrifos 15G Use on Peanut, 1987-89 Average
[Total = 1,109,873 lb a.i.]



Based on States reporting.

Starting in late June and continuing through August in the Virginia-Carolina region, adults lay eggs in peanut crops. Heavy infestations of these insects are a consequence of clay soil type, a high content of organic matter, and adequate rainfall (Brandenburg, 1991). Preventive rather than rescue treatments are used to control southern corn rootworm larvae. Insecticidal applications are justified in this region where fields have a history of southern corn rootworm problems and the soil organic content is above 1.0 to 1.5 percent (Brandenburg, 1991). Insecticides used for control of southern corn rootworm are usually applied at the early pod stage (R1 to R3) of peanut growth; however, application during the flowering stage is encouraged in some States (Brandenburg and Hertl, 1990). Early application provides additional benefits in the Virginia-Carolina region, such as early control of leafhoppers, suppression of white mold, control of lesser cornstalk borer (if conditions are dry), and reduced plant injury (since the centers of the rows are still open) (Brandenburg, 1991).

The sweetpotato whitefly, *Bemisia tabaci* (Gennadius), tobacco thrips, *Frankliniella fusca* (Hinds), and the western flower thrips, *Frankliniella occidentalis* (Pergande) are potential new primary pests. These two thrips species are implicated as vectors of tomato spotted wilt virus in peanut. However, none of these insects are listed on the chlorpyrifos 15G or 4E label.

Secondary Pests

Secondary insect pests that are controlled with chlorpyrifos or its alternatives include the white grubs (Scarabaeidae) and wireworms (Elateridae). Both of these pests occasionally damage peanut fields. Plant injury from these insects occurs on underground structures, including pods, stalks, and taproots. The life cycle of these pests ranges from 1 to 3 years.

Economic problems caused by white grubs and wireworms usually are associated with peanut following tobacco, pasture, or sod, which are their preferred hosts. Cultural control (waiting 2 years after tobacco, pasture, or sod production) reduces the likelihood of damaging infestations of wireworms or white grubs.

Another secondary insect pest that damages peanut occasionally in Texas, Georgia, and Alabama is the burrowing bug, *Pangaeus bilineatus* (Say). Feeding by this insect causes kernels to be bumpy, discolored, and off-flavored (Smith and Pitts, 1974). Quality discounts have been reported to reduce prices by $125.00 per ton (USDA, 1966). Nymphs and adult bugs feed on mature pods by piercing the pods and feeding on the kernel inside. More mature pods generally sustain heavier damage (Smith and Pitts,1974). Kernel damage, called "pitting," causes yellow to dark brown spots on the kernel. Economic losses from this pest occur from downgrading of peanuts when marketed.

Plant Diseases: White Mold

Wells (1980) reported white mold (southern stem rot or blight, *Sclerotium rolfsii* Sacci) as the peanut disease causing the greatest yield losses in the United States. Researchers in Georgia (Csinos, 1984) estimated a 10 percent loss of crop value, or about a $40 million loss yearly from white mold.

White mold is the only plant pathogen that appears on the chlorpyrifos label. Chlorpyrifos is used during pegging when disease symptoms first appear. Antifungal activity of insecticides against white mold fungus has been well documented (Backman and Hammond, 1981; Rodriguez-Kabana et al., 1976a; Hagan and Weeks, 1984; Rodriguez-Kabana et al., 1976b).

Initially, white mold causes plant branches to yellow and wilt. Eventually, entire plants become blighted and all of the aboveground portions turn brown and die. Prior to this browning of the stem, dead areas or lesions appear at the base of infected stems. If adequate moisture is available, fungal mycelia appear at the base of the plant near the soil surface. This fungal growth is stringy in appearance and may contain numerous brown, birdshot-sized balls (sclerotia) on the lower stems and leaf litter. These sclerotia first appear white, then turn from tan to black, resembling a mustard seed (Sholar et al., 1991; Bailey, 1991). Injured or decayed pegs account for the greatest losses in yield. Primary cultural controls for white mold have included crop rotation and deep plowing of land prior to planting. In addition, several authors suggest avoidance of dirting plants during cultivation and use of fungicides and/or insecticides at pegging time (Csinos, 1984; Sholar et al., 1991; Bailey, 1991).

PEST MANAGEMENT

Current Chemical Usage

Insects—Results of the National Agricultural Pesticide Impact Assessment Program (NAPIAP) survey indicate that chlorpyrifos is used to some degree in all States producing peanut crops. The most common usage of chlorpyrifos occurs in Florida peanut production for soil insect control (65 percent), while less than 1 percent of the total peanut acreage is treated with chlorpyrifos in New Mexico. Based on the NAPIAP survey, chlorpyrifos is usually applied by ground equipment in a band, from pegging to 30 days after pegging. Regardless of treatment usage, most chlorpyrifos is applied at a rate of 2.0 lb a.i. per acre. An estimated 1.1 million lb of chlorpyrifos 4E and 15G were used for insect control in production of peanut annually from 1987 to 1989. Less than 1 percent of the total U.S. peanut acreage is treated with chlorpyrifos 4E as a preplant broadcast application for wireworms.

The lesser cornstalk borer and the southern corn rootworm larvae are the primary insect pests for pegging application of chlorpyrifos on peanut crops in the Southeast and Virginia-Carolina regions. In the Southwest, approximately 7,000 acres are treated with chlorpyrifos. In Oklahoma, chlorpyrifos is applied for the lesser cornstalk borer and the southern corn rootworm larvae, while in Texas, white grubs and burrowing bugs are the target pests. These usage amounts of chlorpyrifos may increase with continued pressure from these pests and the loss of alternative chemicals, such as diazinon. Currently, only stocks of diazinon with a white grub label are used. These stocks will soon be depleted.

In the Southeast, chlorpyrifos 15G is applied for the lesser cornstalk borer most commonly at 2 lb a.i. per acre. The number of treatments range from one to two per growing season, with a point estimate of one. Treatment frequency for the southern corn rootworm larvae and other insect pests averaged less than one per season in this region. Over the past 3 years (1987 to 1989), chlorpyrifos treatment on peanut for insect control has been the greatest in the Southeast. Chlorpyrifos use in this area constituted about 75 percent of the total amount applied to peanut in the United States. Approximately 24 percent of chlorpyrifos is applied to peanut in the Virginia-Carolina region, and 1 percent of this chemical is applied to peanut in the Southwest region.

Chlorpyrifos and fonofos are the two most common insecticides used for controlling lesser cornstalk borer and southern corn rootworm larvae. Application of ethoprop, carbofuran, and diazinon for controlling soil insects accounts for a small portion of total chemical use.

White mold disease—The NAPIAP survey indicated that chlorpyrifos usage for white mold (southern blight) was similar to its usage for insect pests. Chlorpyrifos is used for white mold control in every State that produces peanut. An estimated 328,962 lb of chlorpyrifos 15G for white mold control was used in production of peanut annually from 1987 to 1989.

The Southeast region leads the United States in the total amount of chlorpyrifos used on peanut, with Alabama leading this area. This region uses approximately 79 percent (260,220 lb) of the chlorpyrifos applied to peanut crops for white mold control. The Southwest and Virginia-Carolina regions applied considerably less of this chemical, accounting for only 16 and 5 percent of the total chlorpyrifos usage, respectively. Chlorpyrifos 15G and its alternatives, when used for controlling white mold, are exclusively applied by ground equipment in a band (6 to 12 inches). Application takes place from flowering to 30 days after pegging and involves 1.0 to 2.0 lb a.i. per acre, with a point estimate of 2.0 lb a.i. per acre. Generally, one application of chlorpyrifos per season is required.

Nationally, chlorpyrifos 4E is not used for white mold or any postemergent application, since this usage was removed from the label in 1987. Several State specialists indicated a suppression of white mold fungal growth by using chlorpyrifos when pest pressure was low. All of the States in the NAPIAP survey indicated that the major constraint in using the primary alternative (pentachloro-nitrobenzene) was its higher cost.

Chemical Alternatives to Chlorpyrifos

Insecticides—Selection of insecticidal alternatives to chlorpyrifos is based on relative efficacy, residual activity, toxicity, and cost. Most of the chemical alternatives are granular formulations, which are applied by ground equipment at or shortly after pegging (i.e., within 30 days). Fonofos is the preferred alternative to chlorpyrifos for all insect control on peanut crops. Ethoprop, diazinon, and carbofuran are also used as alternatives; however, their usage is considerably lower than chlorpyrifos and fonofos.

The major constraints of the alternative chemicals include: inconsistent performance, shorter residuals, and higher human toxicity. Fonofos, ethoprop, and carbofuran are labeled for rootworm control for peanut crops. Ethoprop and carbofuran are used at planting and pegging, while fonofos is labeled only for postplant applications from early flowering to 30 days after pegging. Fonofos is also labeled for lesser cornstalk borer and cutworm control. Additional uses for ethoprop include lesser cornstalk borer suppression and nematode control. Fonofos or Dyfonate 10G and 20G are labeled for use in the Southwest and Southeast areas of the country, respectively. Chlorpyrifos and its alternatives have a wide range of label rates; however, most States use 1.0 to 2.0 lb a.i. per acre and band apply along the row.

Fungicides—Fungicidal alternatives to chlorpyrifos for white mold control are chosen largely on the basis of efficacy. These alternatives are available in granular, flowable, and wettable formulations. Nationally, the primary alternative to chlorpyrifos for treating white mold is pentachloro-nitrobenzene, which is applied by ground equipment as a granular formulation. Application generally occurs from pegging and up to 30 days after pegging (R2 to R5); chlorpyrifos and its alternatives are used primarily for southern blight control.

Alternatives to chlorpyrifos include carboxin, fonofos, ethoprop, and cultural practices. Grichar and Boswell (1987) present a list of cultural practices that assist in reducing or controlling southern blight. Treatment rates of chlorpyrifos for white mold control are 2.0 lb a.i. per acre. Treatment rates for pentachloro-nitrobenzene range from 3.0 to 10.0 lb a.i. per acre, with most applications using 5.0 lb a.i. per acre. Carboxin rates range from 0.5 to 1.12 lb a.i. per acre, with most applications using the highest treatment level (1.12 lb). Fonofos and ethoprop rates are similar to chlorpyrifos rates.

Comparative Performance on Insects

Within the peanut-producing regions, only two States (Texas and North Carolina) indicated comparative performance by an alternative chemical equivalent to chlorpyrifos. They indicated that if fonofos remained available, no appreciable loss of yield or quality would occur as a result of southern corn rootworm larvae and lesser cornstalk borer damage. All other States (including Texas for white grub control) cited a negative effect on yield and quality if chlorpyrifos 15G were not available. This effect was particularly pronounced in the Southeast region, which is the greatest peanut production area. In this region of the country, alternatives to chlorpyrifos for insect control ranged in comparative performance from 12.5 to 30 percent loss in yield and/or quality. In the Virginia-Carolina region (except for North Carolina), comparative performance of alternatives to chlorpyrifos for insect control ranged from a 3 to 5 percent reduction. The Southwest region recorded the lowest use of chlorpyrifos and the least negative effect from use of alternatives. Both Texas and New Mexico cited little if any effect if chlorpyrifos is lost, assuming present alternatives remain available. Conversely, Oklahoma suggested a loss of 1 to 3 percent if chlorpyrifos is discontinued.

Southeast—Responses to the NAPIAP questionnaire indicate that the lesser cornstalk borer is the major insect pest in the Southeast region. Yield losses from the lesser cornstalk borer have exceeded 70 percent in severe outbreaks (Smith and Barfield, 1982). In addition, Suber et al. (1982) estimated lesser cornstalk borer damage to peanut crops in Georgia was $25 million in 1980.

In the Southeast region, respondents cited consistency and residual activity as the major reasons for choosing chlorpyrifos over the next two commonly mentioned alternatives (fonofos and ethoprop). Mack and Miller (1990) demonstrated a longer residual for chlorpyrifos over fonofos and ethoprop. Thirty-nine days after chemical treatment, mean percent survival of lesser cornstalk borer larvae for chlorpyrifos, fonofos, ethoprop, and the untreated control was 4, 88, 85, and 89 percent, respectively. Furthermore, chlorpyrifos was the only insecticide that reduced larval survival at 53 days after application and provided control for more than 14 days in both years of the test (Mack and Miller, 1990; Mack et al., 1991b). Treatment with chlorpyrifos also produced significantly greater yields in both years of one test (Mack et al., 1991b). In 1988, at the Alabama location, crop yield with chlorpyrifos use was approximately 35 and 28 percent more than when fonofos and ethoprop were used, respectively. In 1989, approximately 34 percent less yield was recorded for fonofos and ethoprop as compared to chlorpyrifos in this same location. In contrast, during this same study, use of chlorpyrifos produced similar results to fonofos and ethoprop in Florida (Mack et al., 1991b).

Additional studies by Funderburk et al. (1987) and Gilreath et al. (1987) indicated some minor increases in yield from using chlorpyrifos on peanut over fonofos and ethoprop. The yield differences, however, were not statistically significant for these Florida trials. Gilreath et al. (1989) also evaluated chlorpyrifos, fonofos, and ethoprop for lesser cornstalk borer control. After treatment, no differences were noted in subsequent trapping of adults. Yields were, however, significantly higher for chlorpyrifos over fonofos in 1 of 3 years.

Southwest—In Oklahoma, Berberet et al. (1986) attributed a loss of nearly 8.8 lb per acre for each 1 percent of infestation of the lesser cornstalk borer on peanut plants. Berberet et al. (1979) and Smith and Holloway (1979) conducted the first studies that related infestation levels to reductions in yield, thereby establishing economic thresholds for lesser cornstalk borer. In addition, Berberet et al. (1986) compared the efficacy of chlorpyrifos, fonofos, and ethoprop in Oklahoma. In these trials, chlorpyrifos was 21 and 23 percent more efficacious on lesser cornstalk borer than fonofos and ethoprop, respectively. In addition, chlorpyrifos provided 25 and 90 percent more yield than fonofos and ethoprop, respectively. No studies have adequately tested the effects of southern corn rootworm larval populations on peanut in the Southwest; however, occasional outbreaks do occur in high-risk areas.

Smith and Pitts (1974) performed the most recent study which described the pest status of the burrowing bug. In Frio County, Texas, lower peanut grades caused a $138.23 per ton net quality loss from 10 percent damaged kernels in 1971. Smith et al. (1974) evaluated insecticides for control of burrowing bugs. In this test, fonofos, ethoprop, diazinon, and chlorpyrifos were evaluated. Fonofos treatment resulted in the fewest damaged kernels, while the other chemical treatments experienced 27 to 49 percent more damage and 15 to 16 percent more dollar loss per ton (Smith et al., 1974).

Virginia-Carolina region—In this region, unless conditions are dry, lesser cornstalk borer control is rarely needed except in South Carolina (J. W. Chapin, 1991, personal communication). In five replicated on-farm demonstrations in South Carolina, chlorpyrifos 15G increased net returns $79 to $243 per acre using lesser cornstalk borer control. Chapin (1991, personal communication) also reported a 321 to 849 lb per acre yield increase from lesser cornstalk borer control. No alternative insecticides were compared with chlorpyrifos in this study.

The southern corn rootworm larva is the major pest affecting peanut production in Virginia and North Carolina. Herbert (1990a) demonstrated in Virginia a 79 to 533 lb per acre increase in yield from control of southern corn rootworm larvae. This response in yield resulted in a $238.00 to $390.00 increase in value ($/acre). In North Carolina, Brandenburg and Hertl (1990) reported a 26 to 100 percent reduction in southern corn rootworm damaged pods from several insecticide options used at varying growth stages. In this test, all insecticides commonly applied for control of southern corn rootworm larvae provided at least 85 percent reduction in damage. Chlorpyrifos, however, provided the best control.

Comparative Performance on White Mold

Only Florida and Texas cited a negative comparative performance as a result of replacing chlorpyrifos with pentachloronitrobenzene for white mold control. Florida peanut growers consistently experienced significant (10 to 30 percent) yield increase from using chlorpyrifos instead of pentachloronitrobenzene for white mold control (T.A. Kucharek, 1991, personal communication). Use of other chemical alternatives to chlorpyrifos are limited nationally. These alternatives include carboxin, fonofos, ethoprop, and propiconazole (section 18 in Texas). During the past 3 years, none of these alternatives (except propiconazole in Texas) provided an increase in yield or quality over chlorpyrifos for white mold control.

Southeast—Studies in each of the Southeastern States demonstrated that chlorpyrifos reduced white mold in peanut (Kucharek and Edmondson, 1991). Florida, however, is the only Southeastern State that obtained better results from chlorpyrifos versus pentachloro-nitrobenzene or carboxin. These two alternatives are the most commonly cited replacements for chlorpyrifos. In Georgia and Alabama, pentachloronitrobenzene has consistently returned significantly higher yields than chlorpyrifos (Csinos, 1989; Csinos, 1984; Hagan et al., 1988; Hagan et al., 1986; Hagan and Weeks, 1985).

Southwest—Disease problems are more erratic and environmentally driven in the Southwestern United States. In 1990, in one of two locations in Oklahoma, chlorpyrifos provided higher disease control and greater yields than pentachloro-nitrobenzene, carboxin, or propiconazole (Jackson and Damicone, 1991). In Texas, Grichar and Boswell (1987) showed consistently similar yields and white mold control from chlorpyrifos and pentachloro-nitrobenzene. Although propiconazole is not presently registered for use on peanut, they also found that it provided excellent control of southern blight. Yields were comparable to chlorpyrifos and pentachloro-nitrobenzene (Grichar and Boswell, 1987; Grichar, 1987; Grichar, 1988). Propiconazole has been used during the past few years in Texas under a section 18 exemption.

Virginia-Carolina region—Minimal disease control on peanut is needed in Virginia and North Carolina. Preventive treatment with chlorpyrifos for southern corn rootworm larvae on high-risk fields adequately controls low white mold infestations. In South Carolina, disease problems are also variable but more widespread, depending on environmental cues. The primary controls listed in other regions are also used in South Carolina, and all of these controls are comparable in their level of efficacy and yield returns (Drye, 1991, personal communication).

Nonchemical Alternatives

Few nonchemical management alternatives exist for controlling insect or white mold infestations on peanut. Crop rotation, in conjunction with several cultural practices and chemical control, is recommended in the management of white mold problems. Insect problems cannot be managed easily by cultural practices.

Lesser cornstalk borer—Although several authors (Berberet et al., 1986; Stalker et al., 1984; Schuster et al., 1975) have reported cultivars with resistance to lesser cornstalk borer, most agree that differences in susceptibility are difficult to demonstrate in the field. Consequently, all commercially available cultivars are considered susceptible to lesser cornstalk borer damage.

Peanut production on sandy soil without irrigation provides the most favorable habitat for the lesser cornstalk borer (Berberet, et al., 1986; Walton et al., 1964; Luginbill and Ainslie, 1917). Rainfall and/or irrigation are recognized as the primary limiting factors of lesser cornstalk borer populations (All and Gallaher, 1977; King et al., 1961). In addition, Leuck (1967) and Berberet et al. (1986) identified increased lesser cornstalk borer damage in late-planted peanut. This increase occurred because pegging and pod formation coincided with peak populations of lesser cornstalk borer during late summer. Berberet et al. (1986) suggested that this selectivity for late-planted peanut was due to the effects of exposure and drying from a more open plant canopy. This phenological information on the lesser cornstalk borer explains why several States recommend planting early and using early-maturing varieties in an irrigated system.

Southern corn rootworm larvae—Only one State (North Carolina) suggested variety resistance as a means of controlling southern corn rootworm larvae. Unfortunately, this variety (NC-6) is not recommended for light, sandy soils that suffer from drought stress. Therefore, a low percentage (2 percent) of acreage is planted with this variety.

In the Virginia-Carolina region, where southern corn rootworm is a primary peanut pest, several cultural and environmental factors are considered. These considerations include soil moisture, organic matter content, soil type, and field history. Fields with a history of southern corn rootworm problems and a clay soil type with organic matter content higher than 1.0 percent have a high potential for heavy southern corn rootworm larval infestations. In this Virginia-Carolina region, adequate rainfall in late July to early August in these high-risk fields creates a tremendous potential for heavy larval populations of the southern corn rootworm. In this region, southern corn rootworm larval infestations are reduced by avoiding high-risk locations, planting NC-6 when possible, and using a preventive treatment if problem fields are unavoidable.

Because of the little-understood nature of lesser cornstalk borer and southern corn rootworm larvae in peanut, as well as the abundance of the food source available for these insects, biological control organisms (predators, parasites, and pathogens) have so far provided minimal natural regulation of these pest populations. In addition, these biological control agents probably have an insignificant impact in preventing the occurrence of economically damaging pest outbreaks (Berberet et al., 1986; Funderburk et al., 1984).

White mold—All peanut-producing States use several cultural practices to avoid white mold problems. The major cultural method for controlling white mold in peanut is rotation with a nonhost crop. Good rotational crops include corn, cotton, and small grains. Other leguminous crops should be avoided. Length of rotation time is variable (1 to 5 or more years) nationally. Another common cultural practice is moldboard (or deep) plowing of peanut residue. This practice should be done in the spring after the peanut residue in the fall has been lightly disked, burned, or baled. Removal of crop residue and subsequent deep plowing eliminates a fallow season host and reduces the number of sclerotia in the upper soil profile.

Additional management factors that can help reduce southern blight problems include: planting on a bed of soil rather than in furrows; avoiding throwing soil against peanut vines during cultivation; controlling leafspot diseases to prevent defoliation (thereby reducing litter on the soil surface); controlling weeds; and carefully timing the watering in order to allow sufficient drying between irrigations.

Nonchemical management of insect and disease problems for peanut crops is effective and is practiced in some areas with major pest problems. In the Southeast States, these cultural practices are commonly used because of the heavy disease and insect problems existing in this region. However, because of pest infestations, environmental favorability, and the lack of natural control organisms, these States must also continue to rely on chemical treatments for controlling pests on peanut crops.

Pesticide Resistance

Information gathered from respondents and from the available literature indicates that none of the primary target pests in peanut have developed or are developing resistance to chlorpyrifos.

Impact on Beneficial Insects

Recently, Funderburk et al. (1990) evaluated the response of nontarget (pest and beneficial) organisms to soil-applied chlorpyrifos. During 1 year of the 2-year study, these authors found an increased population level of bollworm, *Helicoverpa zea* (Boddie), and a decrease in spider populations. Although there may be a tendency to attribute the bollworm increase to lack of predatory spiders during this 1-year period (1987), bollworm populations never exceeded the levels recorded during the following year (1988), when no differences in bollworm or spider populations occurred.

Integrated Pest Management

Insects—Integrated pest management (IPM) methodologies are available for the lesser cornstalk borer in peanut; however, no refined methods exist for the southern corn rootworm. In addition, because chemical treatment of southern corn rootworm larvae involves preventive protection in high-risk areas, IPM scouting procedures are not used to protect a present-year peanut crop. Assessing the need for preventive treatment in subsequent years can be based on pod damage, organic matter levels greater than 1 percent, and moisture retention. The occurrence of large populations of adult southern corn rootworm during mid-summer also indicates a potential problem (Herbert, 1991).

IPM techniques for controlling lesser cornstalk borer involve monitoring for larvae and calculating a percent infestation (Mulder et al., 1990; Stewart and Crumley, 1990). In addition, Mack et al. (1991a) recently developed and validated a model that allows for monitoring of adult lesser cornstalk borer and a subsequent (1 week later) larval prediction.

Nationally, thresholds based on larval monitoring range from 5 to 15 percent, depending on location, plant development, and whether peanut crops are irrigated or dryland (Mulder, 1990; Stewart and Crumley, 1990). Thresholds for adult lesser cornstalk borer are based on the abundance of moths flushed from at least 30.5m (100 ft) of representative row in a peanut field (Mack et al., 1991a). This method helps scouts decide whether more intensive sampling (larval monitoring) will be required.

White mold—Currently, no IPM-derived thresholds exist for white mold, since preventive or salvage treatments are the only means of control. Preventive treatments are generally recommended for fields with short rotations or those fields that are continuously planted for peanut crops with a history of southern blight incidence greater than 5 percent. Salvage treatments are used for suppression when disease outbreaks occur unexpectedly.

SUMMARY

Southeast—Based on comparative performance and the cost of alternatives (compared to chlorpyrifos) for treating peanut crops, the Southeast would be the area most severely impacted by the loss of this chemical. This cancellation could, in turn, dramatically affect the peanut market nationally, since most of the major production is located in the Southeast. Loss of chlorpyrifos for white mold control would primarily affect Florida, since growers in this State obtain better control with chlorpyrifos than with pentachloro-nitrobenzene. Production costs would also increase, based on the expense of chemical alternatives to chlorpyrifos for white mold control.

Southwest—Peanut losses in Texas, occurring from use of diazinon instead of chlorpyrifos for white grub control, reflect the lack of alternatives available (especially since diazinon stocks are or will soon be gone). Cancellation of chlorpyrifos on peanut in the Southwest region would primarily affect insect control in Oklahoma and white mold control in Texas. New Mexico would not be affected unless viable alternatives during pest outbreaks were unavailable. Because of the increasing cost of pentachloro-nitrobenzene and carboxin for white mold control, production costs would increase or outbreaks would become more common.

Virginia-Carolina region—Chlorpyrifos 15G in the Virginia-Carolina region is crucial to peanut production. Because of the high content of organic matter and clay in the soil, as well as moisture problems in this region, chemical choices should be based on proven residual activity and low water solubility. Chlorpyrifos is not as water soluble as its alternatives, and has a proven track record of residual activity. In the United States, control of white mold would be the least affected in this region if chlorpyrifos were canceled for this use. The increasing costs of viable alternatives, however, could rapidly change the status of chlorpyrifos for white mold control in this region.

Chlorpyrifos and Seed Treatments

Gerald Wilde

INTRODUCTION

Seed treatment insecticides are commonly used to provide protection against several soil-based arthropod pests that affect stand establishment, plant vigor, and yield. The importance of each pest varies with the geography, crop rotation pattern, tillage method, and crop.

Seed may be treated by the company selling the seed or by the grower (planter box treatment). Primary pests that attack seed crops in the United States are the seedcorn maggot, seedcorn beetle, slender seedcorn beetle, and wireworms.

Chlorpyrifos is registered for use as a seed treatment to control the seedcorn beetle, seedcorn maggot, and wireworm on 13 crops: bean, clover, corn, cucumber, dill, mustard, okra, pea, pumpkin, rutabaga, soybean, sugarbeet, and turnip.

The only registered chemical seed treatment alternatives are diazinon, which is registered for corn, succulent peas, and succulent beans; and lindane, which is registered for use on all crops mentioned above for chlorpyrifos except for dill, mustard, and rutabaga. There is no chemical seed treatment alternative for these three crops.

PEST INFESTATION AND DAMAGE

Several factors determine the severity of pest infestation on seed. These factors include cropping sequence, weather, soil type, tillage practices, and planting date. As tillage is reduced, there is a greater incidence of pests causing stand reductions (Gregory and Musick, 1976). When crops follow sod, small grains, clover, or alfalfa in the rotation, there is a greater chance of problems with wireworms (Elateridae). When crops are planted where manure or cover crops have been partially buried, seedcorn maggot, *Delia platura* (Meigen), may be a serious threat. Delaying planting may also result in greater problems with the seedcorn maggot. Cool weather that delays seed germination increases the likelihood of pests that attack seed, which in turn affects stand establishment. Certain pests, such as some species of wireworms, are more abundant in sandy soils. In some crops, the commonly used pest management practice for providing early season protection of germinating seeds is the use of a seed treatment.

PEST MANAGEMENT

Current Chemical Usage

Major seed treatment companies and State scientists, in States where a significant acreage of the crops discussed in this chapter are grown, were surveyed to determine insecticide usage in seed treatments. Results are summarized in Table 20.

Table 20. Percent of planted seed treated with insecticide seed treatments on selected crops[a]

Crop	Area Planted With Treated Seed (*percent*)	Area Planted (*1,000 acres*)	Area Planted With Treated Seed (*1,000 acres*)
Corn			
(Field + Silage)	5	71,387	3,569
(Sweet)	25	792	198
Soybean	0	58,870	0
Bean			
(Dry + Processing)	90	1,716	1,544
Clover	0	[b]—	0
Pea (Processing)	75	284	213
Sugarbeet	0	1,327	0
Cucumber (Pickle)	[b]—	119	—
Mustard	[b]—	—	—
Okra	[b]—	—	—
Dill	[b]—	—	—
Rutabaga	[b]—	—	—
Turnip	[b]—	—	—

[a]Based on survey of seed treatment companies, consulting firms, and university personnel.
[b]Not known or acreage minimal.

Source: Three major seed treatment companies (Gustafson, Inc., Dallas, Texas; Wilbur-Ellis, Fresno, California; Trace Chemicals, Inc., Pekin, Illinois); a consulting firm (Technomics Consultant, Inc., Deerfield, Illinois); and State scientists where significant amounts of seed crops are grown were surveyed to determine the current usage of seed treatments.

The percent of seed intended for planting that is treated is high in crops like bean (dry and processing) and pea (processing); low in sweet corn; and extremely low in field corn, soybean, sugarbeet, and clover. Loss estimates on the high-use crops (bean and pea) suggest that an average of 10 percent of the acreage planted would have to be replanted if seed treatments were not available. Replant costs are considerable in these high-value crops. At $40 per acre for replant costs, there would be an annual loss of $7,028,000 if seed treatments were not available (D. Landis, 1992, personal communication). A 5-year study on dry beans revealed that, on the average, a seed treatment resulted in a 15 percent difference in yield (D.M. Noetzel, 1992, personal communication). Net profit of about $200 an acre is sought in these crops (bean and pea); with a loss of $30 per acre, the annual loss from reduced yields would be $52,710,000 if no seed treatments were available on these crops.

While the percentage of field corn infested by seed-attacking pests is low (because of the high acreage planted), many acres are planted with treated seed. When wireworm populations occurred in the field, stand losses of 30 percent were frequently noted (McBride, 1980-82). In a series of tests conducted on field corn in Texas (1983-85), increases in yield from seed treatment with lindane resulted in an average added return over treatment cost of $17.72 per acre (Parker, 1983-85). If such a return is applied to 1 percent of corn acres planted, a conservative estimate of annual increase would be $12,649,776.

Chemical Alternatives to Chlorpyrifos

There are no effective postplanting rescue treatment alternatives. Lindane is registered as a seed treatment for the same crops as chlorpyrifos except for dill, mustard, and rutabaga. Diazinon is registered for corn, pea, and bean.

Some of the insecticides applied at planting for the control of southern corn rootworm larvae, *Diabrotica undecimpunctata howardi* Barber, on corn are also effective against the seed-attacking insects. These insecticides are usually more effective than chlorpyrifos seed treatments when high wireworm populations occur; examples include tefluthrin, carbofuran, terbufos, phorate, and fonofos. However, these treatments are much more expensive ($12 per acre) than seed treatments (approximately $1 per acre). Granular systemic insecticides, primarily terbufos and carbofuran, are also used routinely in sweet corn production in the Eastern and Northeastern United States to control the corn flea beetle, *Chaetocnema pulicaria* Melsheimer. Control of this insect is important because the corn flea beetle transmits the causal organism which is responsible for Stewart's wilt. Granular planting-time treatments are also frequently used to control sugarbeet root maggot, *Tetanops myopaeformis* (Roder), on sugarbeet as well as to control the seed-attacking pests.

Comparative Performance

Stand counts from insecticide screening trials indicate that diazinon, chlorpyrifos, and lindane are equally effective in controlling soil pests that attack seed (McBride, 1980-82; Parker, 1983-85). One study in Iowa, however, suggested that diazinon is more effective than lindane in controlling the slender seedcorn beetle, *Clivina impressifrons* LeConte. Also, diazinon is not labeled for wireworm control. Chlorpyrifos has replaced diazinon use in dry bean crops. Seed treatment usage of chlorpyrifos is about 0.2 percent of the total product usage.

Nonchemical Alternatives

No nonchemical pest management strategies are known for seed and seedling protection of bean and pea.

Pesticide Resistance

With the currently registered insecticides that are available for use as seed treatments, no cases of pest insecticide resistance have been identified. The potential for pest resistance would likely increase if only a single compound was available as a seed treatment.

Integrated Pest Management

Integrated pest management includes the use of bait stations as a method of predicting the need for wireworm control. Bait stations are established 2 to 3 weeks before planting, and seed treatment is recommended if captures average more than one wireworm per trap. No practical means are available for predicting populations of seedcorn maggot or seedcorn beetle, *Stenolophus lecontei* (Chaudoir). However, treatment for the seedcorn maggot is strongly recommended in fields where manure or cover crops have been partially buried by recent tillage.

FUTURE PEST MANAGEMENT OPTIONS

Increased efforts are currently being made to control corn rootworm with methods other than soil-applied insecticides. Several midwestern States are involved in a program to control adults with starch-borate granules impregnated with cucurbitacin and a very small amount of carbaryl (Meinke, 1990). If this approach is successful (and adopted), the occurrence of pests that attack seeds is likely to increase, since 38 percent of the field corn acreage is currently treated with a granular planting-time insecticide that controls seed-attacking insects as well as corn rootworm larvae. In order to reduce the use of granular planting-time insecticides, emphasis is also being placed on crop rotation to control corn rootworm. Such a practice will probably result in an increase in stand reductions due to seed-attacking pests.

SUMMARY

Seed treatments are the main protection against pests that attack seed. These pests include the seedcorn maggot, seedcorn beetles, and wireworms. A high percentage of planted seed for beans and peas is treated with diazinon or chlorpyrifos. Diazinon, chlorpyrifos, and lindane are the insecticides used as seed protectants. If the registration of chlorpyrifos is canceled, there will be a 30 percent reduction in the rotational options used to reduce resistance development.

Chlorpyrifos Use on Sorghum

Marlin E. Rice

INTRODUCTION

Sorghum, *Sorghum bicolor* (L.) Moench, is grown on 11.6 million acres in the United States. Sorghum is planted across the southern portion of the country from Florida to California and as far north as South Dakota.

Both liquid and granular formulations of chlorpyrifos are applied to control below-surface and above-surface insect pests, most notably greenbug, sorghum midge, chinch bug, southern corn rootworm, corn leaf aphid, yellow sugarcane aphid, lesser cornstalk borer, corn earworm, sorghum webworm, and fall armyworm.

Chlorpyrifos is registered for use on sorghum as 15G (granule) and 4E (emulsifiable concentrate) formulations. For usage details, see Figure 11. Application rates of the liquid formulation range from 0.25 lb a.i. per acre for sorghum midge, 0.25-0.5 lb for aphids, and 0.5-1.0 lb for chinch bug and the stalk-boring/panicle-feeding complex of caterpillars. Chlorpyrifos sprays for chinch bug and lesser cornstalk borer are directed toward the base of the plant with sufficient water to ensure coverage in an 8 to 12 inch band. Chemical injury may occur if the 4E formulation is applied to drought-stressed sorghum within 3 days of rain or irrigation. Label restrictions include not using the sprayed crop for grain, forage, hay, or silage within 30 days after application of 0.50 lb a.i. per acre, or within 60 days if higher rates are used. Sweet varieties of sorghum should not be sprayed. No more than 1.5 lb of chlorpyrifos should be applied per acre per season.

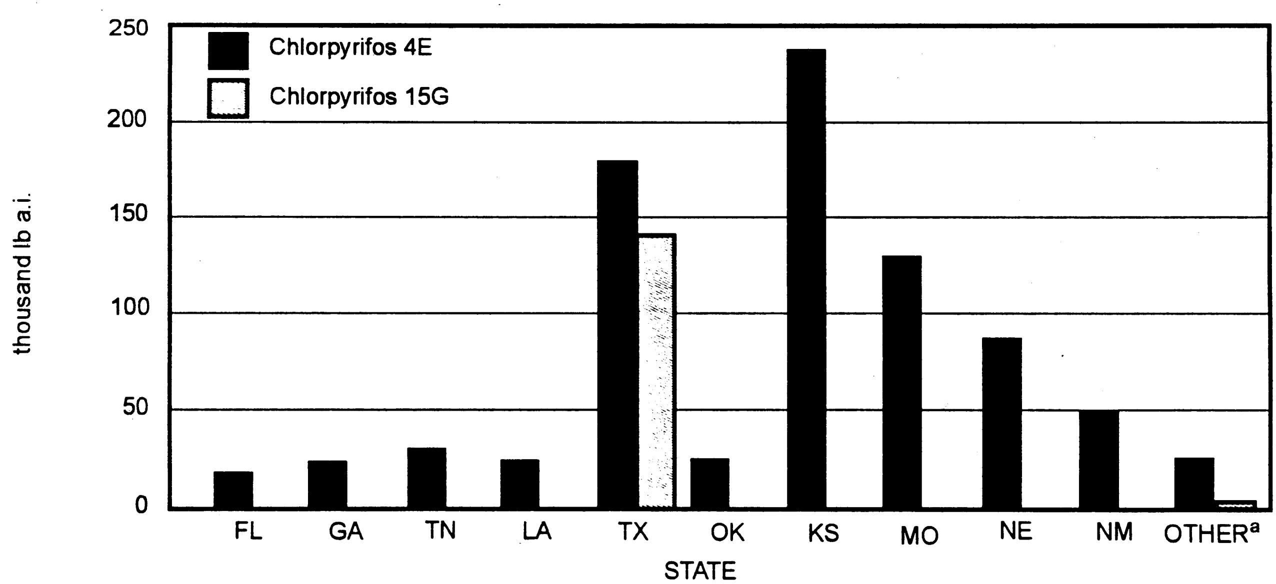
Insect pests listed on the 15G label include lesser cornstalk borer, corn rootworm, cutworms, fire ant, and chinch bug. Application rates vary from 4 to 12 ounces of formulation per 1,000 feet of row. The product should be applied in a 6- to 8-inch band over the row and lightly incorporated. No more than one application per growing season should be made.

PEST INFESTATION AND DAMAGE

Primary Pests

Young and Teetes (1977) reviewed the economically important arthropod pests of sorghum. These authors stated that two insects, the greenbug, *Schizaphis graminum* (Rondani), and the sorghum midge, *Contarinia sorghicola* (Coquillett), were key pests because they "are serious, perennially occurring, persistent species that dominate control practices; in the absence of deliberate human intervention, the pest populations commonly exceed the economic-injury level each year, often over wide areas."

Figure 11. Chlorpyrifos 4E and 15G Use on Soybean, 1987-89 Average
[Total 4E = 841,332 lb a.i.; Total 15G = 144,796 lb a.i.]



[a]Other:
4E = AL,AZ,CA,CO,IL,IA,MS,NC,SC,SD
15G = AZ,GA,IL

Greenbug injury can occur during any part of the growing season, from emergence to soft dough (Fuchs et al., 1988; Brooks and Higgins, 1991). Seedling plants are very susceptible to greenbug damage and can be killed or stunted. If the plant lives, continued feeding can remove water and nutrients; destroy plant cells (which results in leaf chlorosis that eventually leads to necrosis); and transmit viral diseases that reduce yields (Hoelscher et al., 1987).

In Texas, sorghum midge is one of the most damaging insects to sorghum (Fuchs et al., 1988). Females lay eggs in flowering heads, and the larvae subsequently consume the developing seed.

The chinch bug, *Blissus leucopterus leucopterus* (Say), is more of a problem in the Midwest, and can heavily damage or kill young sorghum. During 1989, Nebraska sorghum producers in high-risk counties reported a 15 to 20 percent yield reduction (Spike, 1990). Crop loss was estimated at $11.3 million (Spike et al., 1991).

Secondary Pests

The Banks grass mite, *Oligonychus pratensis* (Banks), is a secondary pest that may be present in sorghum fields, but is generally found below damaging levels (Young and Teetes, 1977). Secondary pests may increase to densities that exceed economic-injury levels, often as a result of changes in cultural practices or insecticide usage against a key pest. Erratic control has been observed with all of the recommended miticides in the more arid regions of western and northern Texas (Fuchs et al., 1988).

A number of insects are categorized as occasional pests. These pests "cause economic damage only in localized areas or at certain times" and "are usually under natural control and exceed the economic injury level only sporadically" (Young and Teetes, 1977). These insects include white grubs, *Phyllophaga* spp.; wireworms, *Eleodes* spp., *Conoderus* spp., and *Aeolus* spp.; the beet armyworm, *Spodoptera exigua* (Hubner); the southwestern corn borer, *Diatraea grandiosella* Dyar; the sugarcane borer, *Diatraea saccharalis* (F.); chinch bug; corn earworm, *Helicoverpa zea* (Boddie); sorghum webworm, *Nola sorghiella* Riley; yellow sugarcane aphid, *Sipha flava* (Forbes); corn leaf aphid, *Rhopalosiphum maidis* (Fitch); fall armyworm, *Spodoptera frugiperda* (J.E. Smith); and several species of the true bugs, Pentatomidae, Coreidae, and Lygaeidae. The fire ant, *Solenopsis geminata* (Fabricius) is a secondary pest that affects sorghum.

Sorghum generally is able to tolerate large numbers of corn leaf aphid. Populations of these insects usually decline after the boot stage. On rare occasions, control may be profitable if populations persist or increase in the developing sorghum head (Brooks and Higgins, 1991), especially during drought conditions (Wright et al., 1991).

The yellow sugarcane aphid injects a toxin during feeding and can kill plants in the pre-boot stage. Systemic insecticides (carbofuran and disulfoton) applied at planting will suppress the buildup of populations on young plants. If at-planting insecticides are not used, the crop must be scouted while plants are in the seedling stage, and economic injury levels used to determine the need for rescue treatments (Fuchs et al. 1988).

Fire ants and wireworm larvae feed on sorghum seeds and seedlings in the southern part of the United States (Fuchs et al., 1988). Lindane-treated seed will effectively prevent stand loss from these pests, and is less expensive than granular insecticides applied at planting.

White grub larvae and southern corn rootworm, *Diabrotica undecimpunctata howardi* Barber, can reduce seedling stands. No rescue treatments are available for these below-surface insects (Fuchs et al., 1988). Insecticides applied at planting, either in-furrow or banded, are the only effective treatments in fields where this problem exists.

Several species of true bugs and caterpillars will feed on developing seed, particularly in the Gulf Coast States (Hall et al., 1983). Most registered foliar insecticides are effective in providing control.

PEST MANAGEMENT

Current Chemical Usage

Pesticide usage data from the National Agricultural Pesticide Impact Assessment Program (NAPIAP) survey are listed in Table 21. Results from the submitted data indicate that chlorpyrifos was used on approximately 13.4 percent of sorghum

Table 21. Chlorpyrifos and alternative chemical usage in U.S. sorghum production, 1987-1989

Chemical	Acres Treated[a]	Percent Treated[b]
aldicarb	33,917	0.3
carbaryl	421,061	3.8
carbofuran	1,713,258	15.3
chlorpyrifos	1,497,046	13.4
diazinon	31,439	0.3
dimethoate	793,621	7.1
disulfoton	208,322	1.9
fenvalerate	40,134	0.4
fonofos	48,248	0.4
malathion	194,673	1.7
methidathion	31,534	0.3
methomyl	183,371	1.6
methyl parathion	22,933	0.2
oxydemeton-methyl	75,522	0.7
parathion	1,564,051	14.0
phorate	112,984	1.0
propargite	17,200	0.2
terbufos	540,626	4.8

[a]Source: NAPIAP chlorpyrifos questionnaires from Alabama, Arizona, California, Colorado, Florida, Georgia, Illinois, Iowa, Kansas, Louisiana, Mississippi, Missouri, Nebraska, New Mexico, North Carolina, Oklahoma, South Carolina, South Dakota, Tennessee, and Texas.
[b]Based on 11,204,700 reported acres planted (NAPIAP Chlorpyrifos Questionnaires).

Table 22. Proportion of acreage treated with insecticides for sorghum pests, 1987-1989

Pest Complex	Percent Acres Treated[a]
aphids[b]	34.3
Banks grass mite	1.3
chinch bug	12.3
foliage/head caterpillars[c]	2.2
grasshoppers	1.2
soil insects[d]	14.0
sorghum midge	7.2

[a]Based on 11,204,700 reported acres planted (NAPIAP Chlorpyrifos Questionnaires).
[b]Greenbug, corn leaf aphid, yellow sugarcane aphid.
[c]Corn earworm, armyworm, sorghum webworm, European corn borer, fall armyworm.
[d]Southern corn rootworm, lesser cornstalk borer, southwestern corn borer, or not stated.

acreage in the United States. Of the sorghum acreage treated, chlorpyrifos was used on 19.9 percent of the acres. Nearly one-third of the acres treated were targeted against aphids (Table 22); these insects were predominantly greenbugs.

Chemical Alternatives to Chlorpyrifos

During the survey period (1987-89), 17 registered chemicals were used as alternatives to chlorpyrifos (Table 21). The predominant chemicals were carbofuran, parathion, dimethoate, terbufos, and carbaryl. The other 12 chemicals were used on a more limited basis. Carbofuran, disulfoton, phorate, and terbufos are systemic soil insecticides labeled for at-planting application, and are recommended for greenbug control in some regions (e.g., eastern Kansas), but not in others (e.g., Nebraska or Texas). Concerns against using at-planting insecticides include unnecessary costs, the potential for increased resistance, and an inability to prevent mid- to late-season damage (Fuchs et al., 1988; Brooks and Higgins, 1991; Wright et al., 1991).

Comparative Performance

Sorghum midge—Anderson and Teetes (1990) found that plots treated with chlorpyrifos had significantly less midge damage and higher yields than untreated sorghum; however, plots treated with esfenvalerate had higher yields. Merchant and Teetes (1989) noted that two different rates of chlorpyrifos and a high rate of esfenvalerate resulted in significantly larger yields than unsprayed sorghum. They also concluded that chlorpyrifos performed as well as the two pyrethroids in the study. Robinson and Teetes (1988) found that liquid formulations of chlorpyrifos, cyhalothrin, and tralomethrin all produced levels of sorghum midge damage that were significantly less than an untreated check, but only chlorpyrifos resulted in a yield difference that was statistically greater than the yield from the untreated check. All et al. (1986) also found that sorghum midge was significantly reduced by chlorpyrifos, and that this chemical was equal in performance to several pyrethroids. Excellent control of sorghum midge was obtained with chlorpyrifos in Georgia and Texas, with less damage and control compared to other tested organophosphates and pyrethroids (Fitt and Teetes, 1986; Pendley and Gardner, 1986d, 1986e).

Greenbug—Recently published data on greenbug are limited, but Hein et al. (1988) found that liquid chlorpyrifos significantly reduced greenbug densities. Similarly, liquid chlorpyrifos reduced greenbug populations to levels comparable to those in dimethoate- and fonofos-treated foliage in Nebraska (Peters, 1986c), but chlorpyrifos did not provide a yield advantage over other products in a different test (Peters, 1986b). Similar results were observed by DePew (1984), with no difference in greenbug densities or yields when sorghum was sprayed with chlorpyrifos, carbofuran, fonofos, parathion, or oxydemeton-methyl.

Chinch bug—Chemical control of chinch bug is erratic and largely influenced by both insect density and length in time of immigration. Wright et al. (1991) stated that carbofuran 15G applied in the seed furrow at planting provides the longest protection against small migrating populations of chinch bug. Liquid formulations of seven different insecticides, including chlorpyrifos, were unable to protect young plants from continual migration of large populations of chinch bug into test plots (Peters, 1986a). Three days after treatment, the number of chinch bugs per plant was not significantly less than on the untreated plants, while treatments of carbaryl, carbofuran, cyfluthrin, and cyhalothrin resulted in lower numbers of chinch bugs than the chlorpyrifos treatments (Peters et al., 1990). David et al. (1991) reported the number of chinch bugs per plant when treated with either granules or liquid chlorpyrifos was not significantly different from the numbers found on plants treated with carbofuran, terbufos, or acephate. Parker et al. (1989) noted that sorghum treated with chlorpyrifos granules at planting or treated with granules and a later foliar application of liquid chlorpyrifos resulted in significantly more yield than control plots that were infested with chinch bugs.

Lepidoptera larvae—Both formulations of chlorpyrifos were effective in protecting seedling plants from lesser cornstalk borer and usually provided control that was numerically superior to other treatments (Cheshire, 1986a, 1986b; Cheshire and Slaughter, 1986). Liquid chlorpyrifos significantly reduced populations of sorghum webworm, corn earworm, and fall armyworm, and was equal in performance compared to several pyrethroids (All et al., 1987b). Chlorpyrifos performed as well as acephate, cypermethrin, and cyhalothrin in controlling fall armyworm in Georgia (Pendley and Gardner, 1986a, 1986b, 1986c).

Nonchemical Alternatives

Cultural practices, such as early planting and elimination of alternate hosts, prevent midge damage. Problems with chinch bug occur most often when sorghum is planted adjacent to wheat fields. As the wheat matures and is harvested, the bugs migrate to the greener sorghum (Bauernfeind, 1990). The best prevention for this problem is not planting sorghum into wheat stubble or adjacent to wheat (Brooks and Higgins, 1991).

Pesticide Resistance

Greenbug resistance to organophosphates has been observed with oxydemeton-methyl, disulfoton, and dimethoate since the mid-1970's, and more recently with parathion and chlorpyrifos (Sloderbeck et al., 1991). Greenbug resistance to organophosphates was detected in southwestern Kansas in 1989, but was estimated as occurring in less than 5 percent of the fields. By 1990 nine counties were reporting resistance problems, with 30 percent of the fields, or 50,000 acres, being affected. Bioassays using parathion and chlorpyrifos-methyl detected LD_{50} values that were as high as 220- and 56-fold difference, respectively. Annual insecticide applications are common on irrigated sorghum in southwestern Kansas, and resistance problems are expected to increase in future years.

Impact on Beneficial Insects

In Texas, greenbug tests conducted with chlorpyrifos at a standard rate of 0.25 and 0.5 lb a.i. per acre and a reduced rate of 0.05 and 0.125 lb provided control that was statistically similar, and there was no difference in yields (Smith et al., 1985). However, the reduced rate also decreased beneficial species, such as the parasitic wasp, *Lysiphlebus testaceipes* (Cresson); ladybugs, *Hippodamia* spp.; *Scymnus* spp., and lacewings, *Chrysopa* spp., to densities that were not different from those in plots that were sprayed at higher rates. Other than this report (Smith et al., 1985), the direct impact of any chlorpyrifos formulation on beneficial insects in sorghum is not known. A review of the past seven issues of Insecticide and Acaricide Tests (1987-1991) underscores this absence of information. Chlorpyrifos 15G, due to its formulation, timing of application, and placement is safer to bees than the 4E formulation.

Integrated Pest Management

Effective and economical management of any insect pest requires successful integration of a variety of nonchemical and occasionally chemical control measures that will adversely affect a pest species and reduce its ability to cause crop loss. The following IPM approaches are given for the two key pests and for the one occasional pest.

Sorghum midge—In Texas, Fuchs et al. (1988) recommended that sorghum producers: (1) plant hybrids of uniform maturity early enough to avoid late flowering; (2) follow cultural practices that favor uniform heading and flowering; (3) eliminate johnsongrass both in and outside the field by cultivation and/or herbicides; (4) consider planting midge-resistant sorghum hybrids; (5) daily scout the field for midge during bloom; and (6) use economic injury level charts that consider control costs, crop market value, and the number of midge per panicle before applying an insecticide.

Greenbug—Integrated pest management approaches for controlling greenbug include: (1) planting hybrids that contain resistance to greenbug biotype E; (2) manipulating planting dates, since historically the risk of infestation on seedling plants has been the greatest in fields planted very early or very late; (3) consider planting into no-till or reduced-till fields, because flying greenbugs tend to land more frequently in fields with no plant residue; (4) utilize natural enemies where present; (5) use planting-time insecticides, except in southwest Kansas; and (6) use foliar sprays if infestations reach economic thresholds (Brooks and Higgins, 1991). Early spraying with parathion and possibly chlorpyrifos for greenbug in mite-infested fields may aggravate mite infestations (Brooks and Higgins, 1991). In these situations, spraying should be avoided until necessary, and products with miticidal activity are recommended (Brooks and Higgins, 1991).

In Kansas, predators (primarily Coccinellidae) are able to suppress greenbug densities below economic-injury levels at all stages of sorghum growth from 3-leaf through the boot stage (Rice and Wilde, 1988). The impact of the parasitoid *L. testaceipes* was sporadic, and parasitism was usually not evident until the middle to latter period of the growing season (Rice and Wilde, 1988). Other than avoiding the use of any insecticide in a sorghum field to conserve natural enemies of greenbug, there are no realistic practices that a producer can follow to increase beneficial insects in a sorghum field for the purpose of greenbug control. If 10 to 12 parasite mummies can be found on each infested plant, an insecticide application should be delayed, because the natural enemies in most cases will reduce the greenbug populations (Brooks and Higgins, 1991).

Chinch bug—An annual survey was conducted in Kansas to determine areas that are at high, moderate, or low risk from chinch bug damage. Farmers, especially those in high risk zones, are strongly encouraged to follow an integrated pest management program that incorporates the following practices: (1) avoid planting sorghum adjacent to wheat; (2) consider using a trap crop between any wheat and sorghum that can be sprayed; (3) plant soybeans between wheat and sorghum; (4) choose hybrids (kafir types) that possess tolerance against mid-summer infestations; (5) utilize fertility regimens that encourage early vegetative growth; (6) consider planting-time insecticides with systemic action if planting within 3 weeks of small grain maturity; and (7) examine adjacent wheat for chinch bug infestations and migration (Brooks and Higgins, 1991). If fields develop damaging infestations, foliar-applied insecticides are often needed. Using drop nozzles, apply 20 to 30 gallons of finished spray per acre. Insecticides will not give residual protection against the continued migration from unsprayed areas (Brooks and Higgins, 1991).

SUMMARY

Approximately 67 percent of the reported sorghum acreage is annually treated with an insecticide (some of these acres may be multiple applications) (NAPIAP Chlorpyrifos Questionnaires). Most of the insecticides are targeted against greenbug, sorghum midge, chinch bug, and a soil insect complex including southern corn rootworm and lesser cornstalk borer. Available research data suggest that insecticidal formulations containing chlorpyrifos are as effective as most alternative insecticides in controlling sorghum midge, greenbug, and lesser cornstalk borer. The performance of chlorpyrifos in controlling chinch bug is more erratic. Although chlorpyrifos is one of most effective insecticides against sorghum pests, opinions expressed by NAPIAP survey respondents suggest that cancellation of this product would have minimal overall impact on future yields. Most States, however, indicated that there would be a 0 to 3 percent loss in quality. South Carolina reported a 0 to 20 percent yield loss, Georgia 10 percent, and the remaining States reported a potential loss of less than 5 percent, with eight States anticipating no yield loss at all (Table 23).

Cancellation of chlorpyrifos would likely result in increased usage of parathion, carbofuran (4F), dimethoate, disulfoton, and fonofos for greenbug; parathion, malathion, esfenvalerate, and disulfoton for sorghum midge; carbaryl and carbofuran (4F) for chinch bug; and terbufos for the soil insect complex. Major constraints listed by the survey respondents to using alternative insecticides included greater expense, shorter residual control, greater human toxicity, and less effectiveness.

Table 23. Estimated sorghum yield and quality reduction if the registration of chlorpyrifos is canceled.[a]

State	Estimated Yield	Reduction in Quality *(percent)*
Alabama	0	0
Arizona	5	0
California	0	0
Colorado	0	0
Florida	2-4	20-90
Georgia	10	25
Illinois	0	0
Iowa	0	0
Kansas	0	0
Louisiana	0-3	0
Mississippi	0-2	0
Missouri	0	0
Nebraska	1	1
New Mexico	0-5	0
North Carolina	[b]---	---
Oklahoma	2-4	1-3
South Carolina	0-20	0
South Dakota	0	0
Tennessee	[b]---	---
Texas	[b]---	---

[a]Source: NAPIAP chlorpyrifos surveys
[b]no data provided.

Chlorpyrifos Use on Soybean

Ken Ostlie

INTRODUCTION

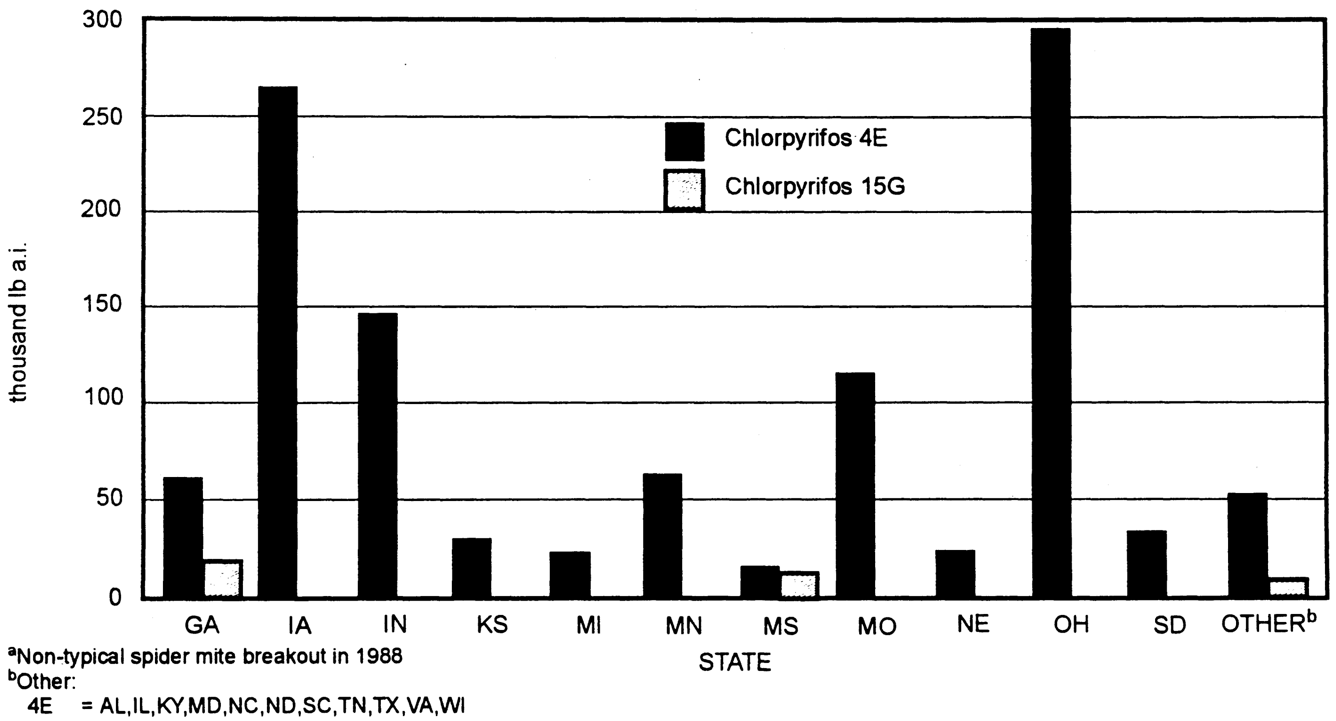
Soybean, *Glycine max* (L.) Merrill, has had a phenomenal increase in production since its introduction into the United States in the 1920's. This increase has earned soybean the title of "the golden bean of the 20th century." Annual production of nearly 2 billion bushels occurs on more than 59 million acres in 29 States. This production can be divided into three geographical regions: Midwest, Delta, and Atlantic Coast. Each region differs in production practices, associated pest spectrum, and severity of pest pressures.

The Midwest region accounts for the overwhelming proportion of national production (81 percent), with six States accounting for 66 percent: Illinois, Iowa, Minnesota, Missouri, Indiana, and Ohio. Other States in this region include: Nebraska, South Dakota, Kansas, Kentucky, Michigan, North Dakota, Oklahoma, and Wisconsin. Soybean in the Midwest yielded 33.8 bushels per acre in the top six States and 30.8 bushels per acre across the entire region (1987-89 average). The Delta region, including Arkansas, Mississippi, Louisiana, Tennessee, and Texas, accounted for 11.4 percent of the national production, with an average yield of 24.6 bushels per acre. The Atlantic Coast region, including North Carolina, Georgia, South Carolina, Alabama, Maryland, Virginia, Delaware, New Jersey, Pennsylvania, and Florida, produced 7.6 percent, with an average yield of 26.2 bushels per acre.

While soybean was initially considered to have few arthropod pest problems, in recent years various arthropods have increasingly been recognized by farmers to be an important factor in limiting further growth in soybean yields. Yield losses from arthropod pests have been estimated at 9 percent. While no key pests exist, insect outbreaks are often managed using insecticides, including chlorpyrifos.

Chlorpyrifos is registered on soybean as two formulations, a granular 15G and a liquid 4E, for at-planting or postemergence control of 15 arthropod pests. For usage details, see Figure 12. Three use patterns emerge: 15G applied to the soil, 4E applied to the soil, and 4E applied to the soybean foliage. Soil applications of 15G at 8 oz per 1,000 row-ft or 4E at 1 to 2 pt per acre control lesser cornstalk borer or cutworms. Soil applications may be made at planting or postemergence when insect injury is first noted. Foliar applications of 4E, at rates ranging from 0.5 to 2 pints per acre, are labeled for primary pests such as the corn earworm, velvetbean caterpillar, and southern green stink bug; secondary pests such as the bean leaf beetle, Mexican bean beetle, green cloverworm, and spider mites; and minor, or incidental, pests such as cutworms, grasshoppers, saltmarsh and woollybear caterpillars, European corn borer, or armyworms. Postemergence foliar applications by ground, air, or chemigation are justified when field counts indicate that damaging insect populations are present or developing, with further treatment being imple-

Figure 12. Chlorpyrifos 4E and 15G Use on Soybean, 1987-89[a] Average [Total 4E = 1,135,772 lb a.i.; Total 15G = 41,284 lb a.i.]



[a]Non-typical spider mite breakout in 1988
[b]Other:
4E = AL,IL,KY,MD,NC,ND,SC,TN,TX,VA,WI
15G = FL,SC

mented as needed (e.g., spider mites—a second application 3 to 5 days later).

PEST INFESTATION AND DAMAGE

As an introduced crop, soybean is relatively free from attack by introduced pests. Most insect pests are Nearctic (North American) or Neotropical (South American), with a few cosmopolitan species. Most insects adapted to soybean after its introduction to this country. Colonization of soybean by native species came in three waves: The first were general feeders, such as grasshoppers, cutworms, woollybear caterpillars, thistle caterpillars, and stink bugs (Plataspidae). The second were insects that adapted from wild legumes, such as Mexican bean beetle, *Epilachna varivestis* Mulsant; bean leaf beetle, green cloverworm, *Plathypena scabra* (Fabricius); and potato leafhopper, *Empoasca fabae* (Harris). The third wave included insects that have switched their host preference from other plant families, such as the Japanese beetle, *Popillia japonica* Newman, and blister beetles. The increase in arthropod problems in soybean resulted from three factors: a fourfold increase in market value since the 1970's that enhanced grower sensitivity to insect attack; increased production acreage, which provided more opportunity and resource for adapted insect pests; and the adaptation of new insect pests and/or their increased range.

The nature of the pest complex varies between the regions, with three notable observations: (1) most species are defoliators, and to a much lesser extent, pod and seed feeders, (2) most species are caterpillars and moths, or beetles, and (3) the Atlantic Coast and Delta regions are more similar in pest spectrum, with the Midwest being unlike either of these two regions. The insects attacking soybean are depicted by their feeding niche (i.e., which part of the soybean plant is attacked) as shown in Table 24.

Pest status of soybean insects throughout the United States, adapted from Hammond et al. (1991), is presented in Table 24. Primary pests (rating =1) of soybean in the United States include: corn earworm, loopers, stinkbug complex, and velvetbean caterpillar, *Anticarsia gemmatalis* Hubner. Note that these primary pests occur within the Delta and Atlantic Coast production areas. The Midwest is relatively free of insect pests that must be routinely considered in production decisions. Secondary pests (rating = 2) include: bean leaf beetle, *Cerotoma trifurcata* (Forster); twospotted spider mite, *Tetranychus urticae* Koch; lesser cornstalk borer, *Elasmopalpus lignosellus* (Zeller); threecornered alfalfa hopper, *Spissistilus festinus* (Say); and the Mexican bean beetle. These arthropods pose sporadic or localized threats to production. Other insects listed on Table 24 are minor, occasional (or incidental) pests.

Table 24. Insects attacking soybean as categorized by feeding site or niche

Feeding Niche	Insect	Common Name	Pest Impact Rating[a]
Germinating seeds and roots	*Delia platura* (Meigen)	Seedcorn maggot	3
	Colaspis brunnea (F.)	Grape colaspis	4
	Scarabaeidae	White grubs	4
	Elateridae	Wireworms	3
Lower stem	*Agrotis ipsilon* (Hufnagel)	Black cutworm	3
	Spissistilus festinus (Say)	Threecornered alfalfa hopper	2
	Elasmopalpus lignosellus (Zeller)	Lesser cornstalk borer	2
	Dectes taxanus texanus	(no common name)	4
Leaf blades	*Anticarsia gemmatalis* Hubner	Velvetbean caterpillar	1
	Spodoptera spp.	Armyworms (beet, fall, southern, yellowstriped)	3
	Pseudoplusia includens (Walker)	Soybean looper	1
	Plathypena scabra (F.)	Green cloverworm	2
	Estigmene acrea (Drury)	Saltmarsh caterpillar	3
	Spilosoma virginica (F.)	Yellow woollybear	3
	Cynthia carduii	Painted lady butterfly	4
	Epilachna varivestis Mulsant	Mexican bean beetle	2
	Popillia japonica Newman	Japanese beetle	2
	Melanoplus spp. and other *Acrididae*	Grasshoppers	3
	Empoasca fabae (Harris)	Potato leafhopper	4
	Tetranychus urticae Koch	Twospotted spider mite	2
Pods and seed	*Nezara viridula* L.	Southern green stink bug	1
	Acrosternum hilare (Say)	Green stink bug	2
	Euschistus servus (Say)	Brown stink bug	3
	Ceratoma trifurcata (Forster)	Bean leaf beetle	2
	Helicoverpa zea (Boddie)	Corn earworm	1
	Helicoverpa virescens (F.)	Tobacco budworm	--

[a]Pest impact rated from 1 to 4 as follows: (1) major pest, (2) intermediate pest, (3) minor, occasional pest, (4) incidental pest. Ratings adapted from Hammond et al., 1991.

The biology and management of important soybean insects has been reviewed extensively by Hammond et al., 1991. Information on individual pests can be referenced through the World Bibliography of Soybean Entomology by Kogan et al. (1989) and several specific bibliographies. Illustrations of these insect pests, with brief descriptions, can be found in the American Soybean Association (1988), Kogan et al. (1986), and Kogan and Kuhlman (1982).

PEST MANAGEMENT

Current Chemical Usage

Current insecticide and miticide usage on soybean varies considerably among production regions, with consistently greater use in the Delta and Atlantic Coast regions than in the Midwest region. Respondents from 25 States estimated that 31.4 percent, 34.9 percent, and 12.5 percent of the soybean acreage was treated in the Delta, Atlantic Coast, and Midwest regions, respectively. Primary targets for these insecticide applications varied between regions.

Respondents from the Delta region (5 States) listed the velvetbean caterpillar (n=3), corn earworm (n=3), green cloverworm (n=4), soybean looper, *Pseudoplusia includens* (Walker) (n=3), stink bugs (n=2), twospotted spider mite (n=1), and cutworms (n=1) as the targets of applications on 2.9 million acres. In the core of the Delta region (Louisiana and Mississippi), treated acreage approached 60 percent of the total acreage. However, chlorpyrifos use was very low. Only 0.5 percent of the total acreage (1.4 percent of the treated acreage) received a chlorpyrifos application (99.6 percent 4E, 0.4 percent 15G). Most States in the Delta region did not report any significant use of chlorpyrifos 15G, except Mississippi for lesser cornstalk borer control.

Respondents from the Atlantic Coast region (7 States) listed a diverse assortment of primary target pests, including the corn earworm (n=5), velvetbean caterpillar (n=4), soybean looper (n=4), and stink bugs (n=2), with the bean leaf beetle, green cloverworm, twospotted spider mite, and Mexican bean beetle listed by single States. Insecticides were applied on nearly 1.8 million acres, with chlorpyrifos applied to 1.6 percent of the total acreage (4.6 percent of the treated acreage). The proportion of treated acreage generally increased from north (5 percent in Maryland) to south (50 percent in Georgia and 100 percent in Florida). As with Mississippi in the Delta region, chlorpyrifos 15G use was also reported by Florida, Georgia, Alabama, and South Carolina for lesser cornstalk borer control. Of the total chlorpyrifos use, 15G constituted a higher proportion (22.7 percent) of use in the Atlantic Coast region than in other soybean-producing regions.

Respondents from the Midwest region (13 States) indicated that minimal insecticide use occurred on soybean during typical years. There are no primary pests that need to be routinely considered in soybean production within the Midwest region. However, the Midwest can be characterized by infrequent outbreaks of secondary and minor pests, with occasional outbreak areas spanning portions of several States. The reporting period for this study, 1987 to 1989, was marked by several pest outbreaks, including: grasshoppers in Northwestern States (n=4, North Dakota, South Dakota, Kansas, and Minnesota); bean leaf beetles from Ohio west to Nebraska (n=5); and, most importantly, the twospotted spider mite over most of the region (n=8) (except for negligible problems in North Dakota, South Dakota, Nebraska, and Kansas). No use of chlorpyrifos 15G was reported in the Midwest.

Insecticides were used on an average of 5 million acres in the Midwest during this 3-year period, with the majority of use occurring in 1988. Insecticide use during this period was dramatically above normal, primarily reflecting a spider mite outbreak of unprecedented magnitude. Nearly 10 million acres were treated for twospotted spider mite alone in 1988. A Wisconsin respondent reported that this estimate reflected the spider mite outbreak of 1988, and therefore constituted an atypical or "bad" 3-year sample. The respondent noted that during his 12 years in Wisconsin, this was the only significant foliar spraying of soybean for that period. The contrast between 1988 and a typical year is illustrated by the following examples: Illinois (42 percent in 1988 vs. 1 percent normal); Iowa (36 percent vs. 1 percent); Minnesota (12 percent vs. 0.3 percent); Missouri (11 percent vs. 4 percent); Indiana (22 percent vs. 2.3 percent); Ohio (30 percent vs. 0.6 to 5 percent); and Wisconsin (25 percent vs. 0.5 percent). Normally, twospotted spider mite might cause minor, localized outbreaks every 4 to 6 years, according to an Iowa respondent. In the absence of a major outbreak, only 1.5 million acres of soybean receive an insecticide application under more typical years, with chlorpyrifos 4E accounting for 19 percent of the treated soybean acreage. In contrast, because chlorpyrifos 4E is a preferred product for twospotted spider mite control on soybean, this chemical accounted for 37 percent of the insecticide used in 1988.

Chemical Alternatives to Chlorpyrifos

Numerous registered pesticide alternatives to chlorpyrifos exist for the primary and secondary insect pests of soybean, with two exceptions: the lesser cornstalk borer and the twospotted spider mite. Predominant options for chlorpyrifos 4E against stem, foliar, and pod- and seed-feeding arthropods are presented in Table 25. Few constraints of alternative insecticides were noted by the 25 respondents. Specific examples included concerns about bee toxicity with encapsulated methyl parathion, the mammalian toxicity of methyl parathion and carbofuran, and the Restricted Use status of alternatives.

Chlorpyrifos is the only insecticide labeled against the lesser cornstalk borer on soybean. Lack of effective, labeled alternatives is a primary concern in the South Atlantic region and Gulf Coast, where the lesser cornstalk borer can be a serious pest in dry years on sandier soils. A South Carolina respondent noted that loss of chlorpyrifos 4E and 15G would leave farmers in that region with no viable alternatives for lesser cornstalk borer control. As stated earlier, this insect is the predominant target of 15G use in soybean. Chlorpyrifos 15G use fluctuates with soybean market prices, with several respondents commenting that current use was suppressed because of the relatively low market prices that reduced "preemptive" or "insurance" treatments in marginal risk situations. The primary alternative insecticide for twospotted

Table 25. Pest spectrums of chlorpyrifos 4E and alternative foliar insecticides labeled on soybean

Insecticides[b]	Insect[a]																		
	AW	BLB	BB	CEW	CW	GH	GCW	JB	LCB	MBB	PLH	SGS	LSC[c]	TC	TAH	TSM	VBC	WBC	SMC
chlorpyrifos	*	*	*	*	*	*	*	-	*	*	-	*	-	-	-	*	*	*	*
acephate	*	*	-	*	-	*	*	-	-	*	-	*	*	-	*	-	*	-	-
Bacillus thuringiensis	*	-	-	*	*	-	*	-	-	-	-	-	*	-	-	-	*	-	*
carbaryl	*	*	*	*	*	*	*	*	-	*	*	-	-	*	*	-	*	*	*
carbofuran	-	-	-	-	-	*	-	-	-	*	-	-	-	-	-	-	-	-	-
dimethoate	-	*	-	-	-	*	-	-	-	*	*	-	-	-	*	*	-	-	-
esfenvalerate	*	*	-	*	*	*	*	*	-	*	*	*	$*_c$	*	-	*	-	*	*
malathion	-	-	-	-	-	-	*	-	-	*	-	-	-	-	-	-	-	-	-
methomyl	*	*	-	*	-	-	*	-	-	*	-	-	$*_s$	-	-	-	*	-	*
methyl parathion	-	*	-	*	-	*	*	*	-	*	*	-	-	*	-	*	*	-	-
permethrin	*	*	-	*	*	-	*	-	-	*	*	-	*	-	-	-	*	-	*
thiodicarb	*	*	-	*	*	-	*	-	-	*	-	*	*	-	*	-	*	*	-
sulprofos	*	-	-	*	-	-	*	-	-	*	*	-	-	-	*	-	*	-	-

[a]Insect pests coded as follows: AW: beet, fall or yellow striped armyworm, BLB: bean leaf beetle, BB: blister beetles, CEW: corn earworm, CW: cutworms, GH: grasshoppers, GCW: green cloverworm, JB: Japanese beetle, LCB: lesser cornstalk borer, MBB: Mexican bean beetle, PLH: potato leafhopper, SGS: southern green stink bug, LSC: loopers (soybean or cabbage), TC: thistle caterpillar, TAH: threecornered alfalfa hopper, TSM: twospotted spider mite, VBC: velvetbean caterpillar, WBC: woollybear caterpillars, SMC: saltmarsh caterpillar.

[b]An asterisk (*) indicates one or more EC, F, S or WP formulations with pest insect on label. A dash (-) indicates no mention on label.

[c]$*_c$ denotes cabbage looper only. $*_s$ denotes soybean looper only.

spider mite control on soybean is dimethoate. Restricted Use status of alternative efficacious products is a concern primarily in the Midwest.

Comparative Performance

Insecticide trials generally indicate comparable performance between chlorpyrifos and more widely used products. Equivalent performance against primary, secondary, and minor or incidental pests was reported in Table 26.

Table 26. Comparative performance studies

Target Insect	Source of Information
Primary pests	
corn earworm	Hellman and Patton (1988a,b,c), Herbert (1990b)
velvetbean caterpillar	Andrews and Kitten (1987)
southern green stink bug	Ratchford (1986)
Secondary pests	
bean leaf beetle	Hammond and Dobrin (1982)
twospotted spider mite	Graustein (1987), Hammond (1989), Ostlie and Chaddha (1989a,b)
lesser cornstalk borer	Herbert and Mack (1987), Mack et al. (1991b)
threecornered alfalfa hopper	None located
Mexican bean beetle	Hammond and Nettleton (1984)
green cloverworm	Hammond and Nettleton (1984), Hellman and Patton (1988a)
Minor or incidental pests	
grasshoppers	Noetzel et al. (1990)
dingy cutworm	Cranshaw and Gill (1984)
yellow woollybear	Ragsdale et al. (1984)

The low volume of chlorpyrifos use may seem incongruous with the above performance data, except for two factors. First, and most importantly, chlorpyrifos is not competitively priced with most alternative products. One respondent noted that chlorpyrifos is a poor choice in most instances for soybean insect control. He reported that although chlorpyrifos is generally effective, it is relatively expensive. Estimates from respondents place chlorpyrifos cost at 1.5 to 1.8 times the cost of the predominantly used pyrethroids (esfenvalerate, permethrin, and tralomethrin). Second, chlorpyrifos is not labeled against the soybean looper, a primary pest of the Delta and Atlantic Coast regions. Because lepidopteran defoliators often occur in mixed populations, the poor performance of chlorpyrifos against this pest (Bass et al., 1981; Rohlfs and Bass, 1981; Ratchford, 1986) tends to eliminate chlorpyrifos from consideration. Doubts about the viability of chlorpyrifos as a realistic option for farmers have tended to eliminate it from efficacy trials, making performance data against some pests difficult to find.

However, two situations run contrary to this generalization: first, chlorpyrifos is effective at low rates against the twospotted spider mite in the Midwest, making this chemical cost-competitive with the predominant alternative product, dimethoate; and second, as the only currently labeled product against the lesser cornstalk borer on soybean, chlorpyrifos demonstrates excellent performance (Herbert and Mack, 1987) with its use limited largely by relative costs of control and soybean prices. Other potential granular alternatives currently not labeled on soybean do not perform as well as chlorpyrifos, with the possible exception of fonofos (Mack et al., 1991b).

Nonchemical Alternatives

Biological control—Shepard and Herzog (1985) reviewed the status and limitations of biological control in soybean. Three approaches may have utility in soybean pest management: conservation and enhancement of natural enemies; inoculative release of biocontrol agents; and an inundatory release of biological control agents.

Host plant resistance—As a preventive measure, the potential of host-plant resistance was explored through several State and USDA breeding programs. An early notable success of plant breeding was identifying plant lines resistant to potato leafhopper. The use of pubescent soybeans has relegated the potato leafhopper to the status of an incidental pest. More recent screening efforts have identified three genotypes, PI 171451, PI 227687, and PI 229358, as offering resistance to various foliar feeding insects: the Mexican bean beetle; corn earworm; tobacco budworm, *Helicoverpa virescens* (Fabricius); bean leaf beetle; and striped blister beetle (Hatchett et al., 1979).

Cultural practices—Several cultural aspects of soybean production have been identified as increasing or reducing insect pest pressure: planting date, tillage, row width and crop placement, and rotation. While these cultural practices can reduce pesticide risk to individual farmers, these practices only minimally affect the overall severity or frequency of pest problems within a production area. Therefore, these practices cannot be viewed as a substitute for insecticide use in general or chlorpyrifos in particular.

Pesticide Resistance

Throughout much of the soybean production area in the United States, this crop has lacked key arthropod pests that pose severe, routine production risks and that consequently would be the target of heavy insecticide use. In general, insecticide resistance is not viewed as a potential problem. However, there are two exceptions: the soybean looper and the twospotted spider mite. Insecticide resistance in soybean looper has been well documented (Fellend et al., 1990; Leonard et al., 1990) and was the focus of a workshop (Hamer and Pitre, 1989). Since chlorpyrifos is not labeled against soybean looper and offers poor control in recent trials, loss of chlorpyrifos is unlikely to affect resistance management of this insect.

The twospotted spider mite has demonstrated the propensity to develop resistance against numerous miticides on a variety of field and horticultural crops. In the western areas of the Midwest, miticide resistance of mites in corn is a major concern. In contrast, during the 1988 outbreak, the twospotted spider mite exhibited susceptibility to the insecticides chlorpyrifos and dimethoate, even at low rates of treatment. The reason for this dichotomy has not been researched. Nonetheless, respondents were concerned about resistance if the frequency of spider mite outbreaks and insecticide use increases. Since only two insecticides are labeled, the loss of chlorpyrifos would drastically limit any resistance management.

Impact on Beneficial Insects

McPherson et al. (1987) demonstrated equivalent impacts of chlorpyrifos and alternative foliar insecticides on beneficial predators (spiders, nabids, and bigeyed bugs) in soybean attacked by a mixed population of corn earworm and green cloverworm.

Minimal impact on pollinators is expected from the loss of chlorpyrifos use on soybean for three reasons. First, pollinators are not an integral component of the soybean production system, because soybean is a self-pollinating crop. Second, because soybean is a relatively poor nectar/pollen source, it is not heavily utilized by pollinators. Third, although some alternatives such as encapsulated methyl parathion pose a greater risk to pollinator colonies, these alternatives are not likely to increase in use if chlorpyrifos is lost.

Integrated Pest Management

Integrated pest management of soybean insects is shaped by three major factors: lack of key pests, importance of natural control, and tolerance of insect injury.

Tolerance of insect injury—Soybean has a tremendous capacity to compensate for insect injury. This fact runs counter to the farmer's tendency to overreact to highly visual injury, e.g., defoliation or stand loss. To ensure that insecticides are used only when needed, farmers need to recognize the differences between perceived injury and the actual potential for loss, and thus make pest management decisions accordingly.

Lack of key pests—Pest populations vary among soybean fields from year to year, which makes pest monitoring an extremely important component of any IPM system. In the Midwest, the frequency of pest outbreaks may be so low that a farmer's experience with a given pest may occur in 1 of every 10 years. In contrast to the single-species outbreaks of the Midwest, the Delta and South Atlantic regions are characterized by multiple pest infestations. Ongoing monitoring is required to determine if and when these mixed infestations justify an insecticide application. In these divergent situations, the consequences can be poorly timed insecticide applications, reactionary and excessive use of insecticides, or an unnecessary yield loss from undetected infestations.

Importance of natural control—In either single- or multiple-species outbreaks, natural control is viewed as an integral part of soybean insect management. In the South, the recognition of the role of natural control is reflected by the emphasis on the conservation of natural enemies, which leads to a conservative approach to insecticide use. For example, early-season infestations of green cloverworm have been viewed as beneficial if these infestations lead to epizootics of the fungus *Nomuraea rileyi* on late-season defoliators such as corn earworm or velvetbean caterpillar. Premature intervention with insecticides could lead to multiple applications that would disrupt natural control. In the Midwest, pest outbreaks are viewed as a temporary release from natural control, and insecticides are viewed as a temporary control measure that should cause minimal disruption of natural control.

Recognition of these factors leads to the following basic IPM approach to soybean arthropods:

1. Cultural practices (e.g., planting date, maturity) should be used to minimize the risk of an outbreak.

2. Soybean should be monitored for primary, secondary, and incidental pests as conditions warrant.

3. Advantage should be taken of soybean's tremendous ability to compensate for insect injury (stand loss and defoliation) without loss in yield or quality (i.e., avoid overreacting to injury; tolerate subeconomic injury).

4. Soybean should be treated only when monitoring indicates that a pest population is causing, or is likely to cause, economic loss (i.e., only if it exceeds the economic threshold).

5. Selective insecticides (e.g., *Bacillus thuringiensis*), application method, timing, and minimal rates should be chosen whenever possible in order to cause minimal disruption of natural control.

Insecticide use is viewed as an integral component of IPM in soybean (Hammond et al., 1991), especially given the sporadic nature of pest outbreaks and the current status of host plant resistance or the inundated use of natural enemies such as disease (see above). An IPM approach to soybean insects reduces unnecessary insecticide use, improves timing of warranted insecticide applications, and minimizes crop losses from undetected infestations.

The cornerstone of outbreak detection is monitoring or sampling. The infrequent and somewhat unpredictable occurrence of soybean pest outbreaks taxes routine sampling efforts; therefore, IPM programs can suffer (Herbert et al., 1991). Alternatively, high frequency of required pesticide use can also diminish the value of IPM programs, as in the case of velvetbean caterpillar in Florida (Szmedra et al., 1990). Sampling plans have been worked out for many soybean insects. However, research continues on designing efficient sampling programs for individual pests or their feeding injury. Four developments are likely to improve sampling efficiency. First, sequential sampling plans reduce effort spent on sampling below and above threshold populations of individual pests. Second, an approach called time-sequential sampling can be used to identify populations likely to reach threshold levels (Pedigo and van Schaik, 1984). Third, with infrequent pest outbreaks, pest advisory systems on an area-wide basis identify situations when outbreaks are likely to occur and sampling efforts would pay off (Herbert et al., 1991). Finally, mixed populations of defoliators can be sampled simultaneously by adopting a "guild" approach (Hutchins, et al., 1988), where insect numbers and life stages are transformed into "injury equivalents." (Note: A guild is a group of insects causing similar injury to soybean, e.g., interveinal leaf feeding.) Developments such as these should help to minimize sampling efforts while allowing for the prompt detection of pest outbreaks.

Decisionmaking goes hand-in-hand with sampling. Soybean entomology is noted for its innovation in applying the economic threshold concept. Recent research efforts promise to improve decisionmaking by incorporating plant stress (Ostlie and Pedigo, 1985), likely insect mortality (Ostlie and Pedigo,, 1987), mixed insect infestations using the "guild" concept (Hutchins et al., 1988), and multiple pest (insect, weed, disease, and nematode) stresses (Higgins et al., 1984; Russin et al., 1989). Despite this progress, two areas urgently need to be incorporated in the decisionmaking process: an assessment of natural enemy status and the cumulative effects of defoliation or other stresses over several plant stages. Lacking the ability to incorporate natural control, the overuse of insecticide and excessive suppression of natural enemies can occur. Recognizing the contribution of natural enemies, Pedigo et al. (1986) outlined a conservative economic threshold approach that protects natural enemies as long as possible. Progress in integrating insect management into total crop management has come through computer models such as SOYMOD or AUSIMM (Backman et al., 1989).

Increased adoption of IPM systems and their improvement will likely have minimal effect on chlorpyrifos use, other than to reduce it below its already low levels. Conversely, chlorpyrifos is not an integral component of soybean IPM except for the two situations with lesser cornstalk borer and twospotted spider mite discussed earlier.

FUTURE PEST MANAGEMENT OPTIONS

The prognosis is excellent for improved *Bacillus thuringiensis* toxin formulations, with more predictable and enhanced performance under field conditions. Since lepidopteran defoliators represent a major guild attacking soybean, increased use of this selective insecticide could reduce reliance on broader spectrum pyrethroids and organophosphates. Similarly, the development of disease agents for use as biological insecticides seems likely. Development of preventive pest management tactics such as host plant resistance and cultural tactics will continue. Improved decisionmaking that incorporates multiple species and injury over multiple plant stages and that recognizes the contribution of natural control will tailor insecticide use, whether biological or synthetic.

Comparative analyses of the insect pest spectrum in the United States and other soybean-growing areas reveals several open niches, which reflect the relatively recent, pest-free introduction of soybean into the United States. Examples of these open niches include: no important presence of upper stem or stalk borers, a relative lack of pod borers and aphids, and an attack of the seeds only by generalist seed feeders, e.g., the stink bugs. The presence of unsaturated niches suggests the potential for new pest problems and the temporary or long-term need for insecticides.

SUMMARY

Estimated annual soybean losses occurring from soybean arthropod pest damage are estimated to approach 9 percent. Arthropod problems and resulting management strategies differ among the three production regions: the Midwest, Atlantic Coast, and Delta. A well-developed natural enemy complex, lack of a key pest requiring chronic insecticide use, and the tremendous soybean tolerance to insect injury reduces the reliance on insecticide use. Of the 59 million acres of soybean in the United States, only 4 million or 6.8 percent are treated with an insecticide annually. Chlorpyrifos use on 2.1 million acres (4 percent of soybean acreage) represents a minor portion of the insecticide use. The presence of numerous alternative insecticides for most soybean insects suggests a minimal impact if chlorpyrifos were not available.

Soybean specialists noted two situations that would be significantly impacted if the registration of chlorpyrifos were canceled: lesser cornstalk borer in the Southern United States and the twospotted spider mite in the Midwest and upper Atlantic region. Specific changes that are likely to occur if chlorpyrifos is discontinued:

1. Because chlorpyrifos 15G is the only labeled insecticide for lesser cornstalk borer control, farmers would be left without any insecticide alternatives. Cultural practices do not offer control, and, in some situations, may enhance risk of infestation. Fortunately, this insect is primarily a problem under drought situations or in dry, sandy sites; therefore, the problem is severe locally in the areas of Mississippi, Alabama, Florida, and Georgia. Nationally, a relatively low proportion of the crop acreage would be affected (less than 0.16 million acres or 0.3 percent).

2. Outbreaks of the twospotted spider mite usually occur infrequently. However, a large outbreak in the Midwest in 1988 affected 10 million acres or 17 percent of U.S. soybean production. This outbreak caught growers unprepared, exhausted supplies of chlorpyrifos and its primary alternative (dimethoate), and left States scrambling for alternatives that cost more and were of a greater risk from the environmental and health viewpoints. Untreated yield loss averaged nearly 40 percent in Iowa (Wintersteen, unpublished data) and 25 percent in Minnesota, where the infestation occurred later (Ostlie and Chaddha, 1989a,b). This unprecedented outbreak has left specialists seriously concerned about the cancellation of chlorpyrifos. This cancellation would leave only one labeled insecticide, dimethoate. Four concerns originate from this scenario:

   a. There may be inadequate supplies of dimethoate to meet this unpredictable problem, which would result in uncontrolled infestations and yield loss.

   b. The appearance of resistance to dimethoate is likely, since the twospotted spider mite readily demonstrates insecticide resistance in other crops. With no viable alternative products, even rudimentary resistance-management strategies would not be possible.

   c. Large-scale outbreaks frequently swamp the local farmer's ability to apply pesticides. Loss of a General Use insecticide such as chlorpyrifos removes personal application as an option unless the farmer is a certified private applicator. Throughout the Midwest, a large proportion of the farmers are not certified applicators.

   d. Possible alternative insecticides cost more, pose greater risks to applicator health and nontarget organisms, are less effective, and, in some cases, can cause pest resurgence.

Absence of chlorpyrifos during the outbreak of 1988 would have had a tremendous economic impact. Exhaustion of supplies of efficacious alternatives could have left growers exposed to yield losses up to 40 percent on 3.7 million acres. If available, substitution of less efficacious alternatives (e.g., propargite) would have cost farmers a 7 to 15 percent yield loss on these 3.7 million acres in this situation.

Chlorpyrifos Use on Sugarbeet

Robert L. Stoltz and Dennis D. Kopp

INTRODUCTION

Sugarbeet is grown in 15 States on 1.3 million acres (1987-89 average). During this period more than 26 million tons of sugarbeets were harvested. The average yield nationally was 20.4 tons per acre, with a crop value to producers that exceeded $1.05 billion. According to the 1987 Agricultural Census, more than 8,000 farms produce sugarbeets. Approximately half of the U.S. sugarbeet production is grown on irrigated land in Western States. Dryland sugarbeet production dominates in Michigan, Ohio, Minnesota, and North Dakota (U.S. Department of Commerce, 1987).

Sugarbeet production is a profitable agricultural industry to both growers and sugar processing companies. Two important factors responsible for the profitability of this industry are limits on production, which are maintained by grower contracts with the processing plants, and Federal sugar support prices. Local economies surrounding sugarbeet processing facilities rely heavily on this industry. Sugarbeet production is an essential industry to the economic well-being of several Midwestern and Western States and provides a reliable domestic source of sugar.

Chlorpyrifos is labeled on sugarbeet in granular 15G and emulsifiable concentrate (EC) formulations. For usage details, see Figure 13. Granular applications are used for controlling the sugarbeet root maggot and soil cutworms. Foliar applications are made to control beet armyworm, cutworms, grasshoppers, aphids, and recently, sugarbeet root maggot.

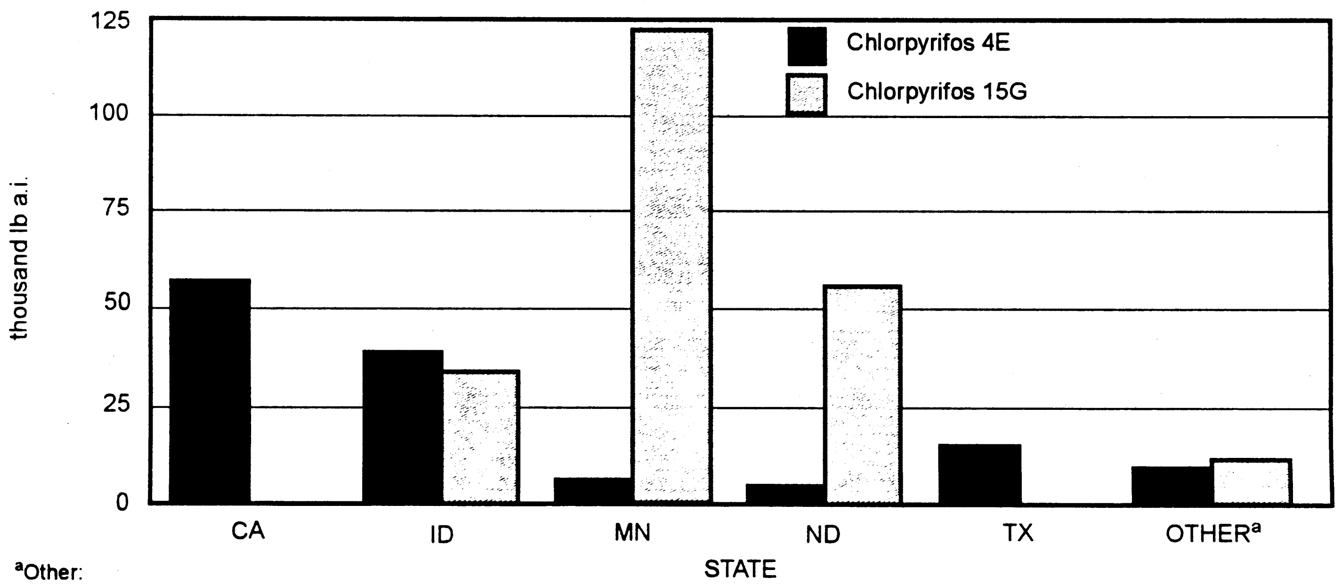
Granular applications are made at rates of 1.5 to 2.0 lb a.i. per acre as a band application at planting. Postemergent granular applications are made at rates of 1.0 to 2.0 lb a.i. per acre in a band over the row and are suitably incorporated from 1/2 to 1 inch. Foliar sprays are applied at rates of 0.5 to 1 lb a.i. per acre.

PEST INFESTATION AND DAMAGE

Primary Pests

The sugarbeet root maggot, *Tetanops myopaeformis* (Röder), attacks the roots of sugarbeets, causing root lesions. Heavy infestations of these insects on seedlings can cause stand loss and reduced vigor and yield (Blickenstaff, 1976). Insect feeding scars on the sugarbeet root may also make the plant more susceptible to invasion by soil pathogens, as well as accelerate rotting in sugarbeet storage piles after harvesting and prior to processing. Approximately 50 percent of the sugarbeet acreage in the United States is attacked by the sugarbeet root maggot, with an average yield loss of 4.93 tons per acre (USDA NAPIAP, 1989).

Figure 13. Chlorpyrifos 4E and 15G Use on Sugarbeet, 1987-89 Average [Total 4E = 130,817 lb a.i.; Total 15G = 231,702 lb a.i.]



[a]Other:
4E = CO,MI,MT,NE,OR
15G = CO,NE,OR,WY

The beet leafhopper, *Circulifer tenellus* (Baker), transmits curly top virus to susceptible or partially susceptible sugarbeet varieties. Early movement of these insects from overwintering sites to young sugarbeet plants can cause stunted plants or plant death.

The green peach aphid, *Myzus persicae* (Sulzer), transmits beet yellows virus. Populations of this insect are seldom large enough to cause direct damage to sugarbeet.

Secondary Pests

The bean aphid, *Aphis fabae* Scopoli, is a mid- to late-season pest that attacks sugarbeet. When populations of this insect are large and/or appear early enough, yield losses occur. Heavy aphid populations cause plants to lose vigor, become weak, and possibly die.

Cutworms, and the armyworm, *Pseudaletia unipuncta* (Haworth), occasionally affect sugarbeet crops. Cutworms often appear as early season pests, cutting plants off at ground level and thereby destroying stands. Armyworm is generally a mid- to late-season pest that causes defoliation of sugarbeet plants.

Spider mites, Tetranychidae, are arthropods that sporadically attack sugarbeet and occur mostly in extra dry or hot seasons. For this reason, spider mites often cause loss of plant vigor late in the season.

PEST MANAGEMENT

Current Chemical Usage

California produces 21 percent of the sugarbeet crop in the United States (1987 to 1989 average). Chlorpyrifos is used widely as a foliar spray to control bean aphid and cutworms in this State. Approximately 27 percent of the acres are sprayed with chlorpyrifos for controlling bean aphid. One percent of the acres needing rescue treatments from caterpillar infestations receive chlorpyrifos applications.

The north-central sugarbeet growing region consists of Montana, Idaho, Colorado, Wyoming, and Nebraska. Approximately 32 percent of the U.S. sugarbeet production occurs in this north-central region, where chlorpyrifos is used to control sugarbeet root maggot. Chlorpyrifos use ranges from 1 percent on treated acres in Montana to 20 percent in Idaho. This chemical is also very important for controlling sugarbeet crown borer, *Hulstia undulatella* (Clemens) in Idaho and Oregon, where more than 20 percent of the sugarbeet crop acres are treated. Cutworm and other caterpillar control in this region is dependent on the availability of chlorpyrifos.

The north-central dryland sugarbeet region consists of Minnesota, North Dakota, Michigan, and Ohio. Chlorpyrifos is used on approximately 25 percent of the planted sugarbeet acreage in North Dakota and Minnesota for control of sugarbeet root maggot. Throughout the dryland sugarbeet region, cutworms cause damage that requires treatment of 1.5 to 10 percent of the planted acreage. Grasshoppers are a sporadic problem in the western portion of this region, but incidence of this pest is minor during most seasons.

Chemical Alternatives to Chlorpyrifos

Registered alternatives to chlorpyrifos for cutworm and armyworm control are trichlorfon, carbaryl, methomyl, and methyl parathion. Alternatives for sugarbeet root maggot are carbofuran, diazinon, aldicarb, terbufos, phorate, and fonofos. For aphid control, diazinon, methomyl, phorate, aldicarb, and methamidophos are used. Alternatives for grasshopper control are carbaryl, malathion, diazinon, methyl parathion, and naled.

Comparative Performance

The sugarbeet root maggot infests about half of the U.S. sugarbeet acreage and has received more attention regarding insecticidal control than other arthropod pests. Granular insecticides have been the traditional method of root maggot control since the 1950's. This pest poses the greatest threat to dryland sugarbeet production; in the northern portion of the Red River Valley of Minnesota and North Dakota, approximately 80 percent of the acreage is treated for this pest (Dregseth, R., 1993, personal communication).

In dryland sugarbeet production, root maggots reach their highest population levels during or immediately following a number of drought years. During dry seasons, granular insecticide performance is most erratic, since adequate seasonal moisture is important for granular insecticidal activation. Thus, in dryland sugarbeet production in the years when the need of insecticidal protection is the greatest, environmental conditions are least conducive to granular insecticide performance. In irrigated sugarbeet land, the more reliable moisture profile accounts for more dependable granular insecticide performance than in dryland acreages.

Granular insecticides have made possible the production of sugarbeet in areas of high maggot pressure. For example, in 1992, sugarbeet root maggot insecticidal trials at Crookston, Minnesota, showed that maggot populations were so high that untreated control plots produced only 7.4 tons of sugarbeets, with high damage ratings. All granular treatment plots produced more than 16 tons, with moderate to low damage ratings (Dregseth, R., 1993, personal communication). These types of data are important to sugarbeet growers, agricultural scientists, and economists in regions where sugarbeet root maggot creates a production problem. In these regions, granular insecticides are needed to produce the quantity and quality of crop necessary to maintain an economically viable operation.

Proper placement of a granular insecticide is essential in obtaining the maximal insecticidal crop protection with the least potential for phytotoxicity to the crop. Currently, the recommended application method for all granular materials used for sugarbeet root maggot control is placement in a lightly incorporated 5-inch band over the row.

Considerable variation in insecticidal trials is related to and dependent on pest pressure, micro-environmental conditions at the trial location, and seasonal climatic conditions during the trial. Rankings listed below are based on trends in performance over a number of seasons' trials rather than a single year's data.

Since the mid-1980's, granular formulations of aldicarb, carbofuran, chlorpyrifos, diazinon, fonofos, and terbufos have been used for sugarbeet maggot control. All granular insecticides significantly outperformed the nontreated control in trials. Prior to the late 1980's, aldicarb was perhaps the top performer, with chlorpyrifos and terbufos competing for second place and the remaining alternatives not performing as well as these insecticides. Since the late 1980's, aldicarb performance has declined. Trials in recent years have shown chlorpyrifos and terbufos providing equivalent performance, with alternatives frequently demonstrating a 3 to 10 percent reduction in yield and quality when compared to chlorpyrifos or terbufos.

In numerous trials in sugarbeet and other row crops, chlorpyrifos 4E provided reliable cutworm control. Chlorpyrifos performs equivalent to or 2 to 5 percent better than alternative insecticides as a rescue treatment for cutworms in sugarbeet.

Nonchemical Alternatives

Using virus-resistant sugarbeet varieties is the preferred method for controlling beet yellows and curly top viruses. Many of these virus-resistant varieties are currently available to producers, and breeding programs are continuing to develop improved resistant varieties. Resistant sugarbeet varieties have not yet been developed for controlling sugarbeet root maggot. Using transgenic procedures, efforts are underway to try to implant the *Bacillus thuringiensis* gene into sugarbeet. This area of research is exciting, but is many years away from practical implementation as a pest management option.

Aphid alarm pheromones offer another potential management tool in future years. These pheromones can be used as foliar sprays and are easy for growers to apply. Early research indicates that these sprays may be helpful in reducing damage from the beet yellows virus, which is vectored by the green peach aphid and bean aphid.

Pesticide Resistance

Resistance has been slow to develop in sugarbeet root maggot, even though organophosphate insecticides have been used extensively in most growing areas for 20 years. This is probably due to the fact that this pest is univoltine and not all crop areas are treated every year. If chlorpyrifos were to be used in rotation with alternative chemicals, it is doubtful that resistance would be a problem. However, as other chemicals that provide alternative modes of insecticidal activity are lost, the potential for insecticide resistance development increases.

Integrated Pest Management

Integrated Pest Management programs are based on scouting as well as tailoring all pest management options for crop protection. Economic thresholds for a number of sugarbeet pests have been developed (Lange and Suh, 1980).

Management strategies for controlling sugarbeet root maggot damage are limited to planting or postemergence preventive treatments with soil insecticides. Some work has been done to establish economic thresholds based on fly numbers (Blickenstaff, 1976; Bechinski et al., 1989). If threshold levels of flies are caught, a rescue treatment is applied. This method has gained only minor acceptance by growers in the sugarbeet industry because of limiting factors such as weather and water availability, and because few postemergent insecticides are available for maggot control. Experimentation in North Dakota and Minnesota in 1991-92 demonstrated that good maggot control and substantial savings can be achieved by implementing this integrated approach to sugarbeet root maggot management (Dregseth, R., 1993, personal communication). Chlorpyrifos may be applied both at planting and postemergence. Other registered granular insecticides used for the fly threshold program are aldicarb and terbufos in the Northwest. Terbufos is used only in the Red River production area because of the rotational restrictions and performance problems with aldicarb in this region.

Cutworms and armyworms occur only in some years. When present, these insects frequently have scattered distribution in individual fields. Effective weed control may play a role in reducing the potential for these insects being a field problem in sugarbeets. It is presently impossible to predict cutworm and armyworm infestations prior to crop stand establishment. Crop monitoring and the appropriate use of rescue treatments are the best pest management options.

The bean aphid migrates to sugarbeet fields in mid- to late summer. Management programs are based on scouting and spraying if a high percentage of plants are infested. Economic thresholds are available for bean aphid, and are based on the percent of plants infested and the length of time prior to harvest (Capinera, 1981). Diazinon and other foliar insecticides are used to control aphids. The green peach aphid transmits beet yellows virus. Growing resistant varieties of sugarbeet is the first line of defense in the management of this disease. Soil insecticides or systemic insecticides applied in a foliar manner in conjunction with resistant varieties are the most effective management approaches to beet yellows virus.

FUTURE PEST MANAGEMENT OPTIONS

The implementation of IPM practices offers great potential for best utilizing existing pest management options for sugarbeet. Few new chemicals are being marketed as alternatives to chlorpyrifos (or to the already existing alternatives to chlorpyrifos). Some new chemistry products (Imidacloprid) show some promise for replacing foliar use of chlorpyrifos in controlling aphids and caterpillars, but these products are not effective against sugarbeet root maggot. Transgenic sugarbeets may be developed to include various biocidal agents that would control pests on sugarbeet, but current estimates are that this development is years in the future.

SUMMARY

Sugarbeet producers will utilize available insecticide alternatives to maintain production; thus, if any one granular insecticide is canceled (but comparably performing alternatives remain available), growers will switch to the available alternatives. Canceling the registration of chlorpyrifos for sugarbeet pest management would have only minor repercussions on U.S. sugarbeet production as long as aldicarb, terbufos, phorate, and fonofos are available as granular formulations to control sugarbeet root maggot. The cost of controlling sugarbeet root maggot in North Dakota, Minnesota, and Idaho would probably increase with the use of alternatives. Control of caterpillars would be diminished because alternatives to chlorpyrifos are less effective. Chlorpyrifos is the material of choice for caterpillar control in many States. Aphid control in California would be greatly affected if chlorpyrifos were not available. Chlorpyrifos is safer for farm workers than its alternatives, and insecticide resistance development would accelerate if this insecticide were lost.

Chlorpyrifos Use on Sunflower

Kenneth Ostlie

INTRODUCTION

Sunflower, *Helianthus annua* L., is one of several oilseed crops grown in the United States. The current sunflower acreage of 1.9 million (1990) represents a 66 percent reduction from a peak of nearly 5.6 million acres in 1979. Competition with other oils (especially imported palm oil), relative consumer demand, and, to a lesser extent, insect pests produced this major decline during the early 1980's. Confection sunflowers grown for human consumption and bird feed make up approximately 22 percent of sunflower acreage. Sunflower production is concentrated in five States: North Dakota, South Dakota, Minnesota, Kansas, and Texas. Figure 14 shows chlorpyrifos usage in three of these States. The Texas sunflower situation is slightly different, with 80 percent of the sunflower acreage targeted for seed production, 15 percent for confection, and 5 percent for oilseed.

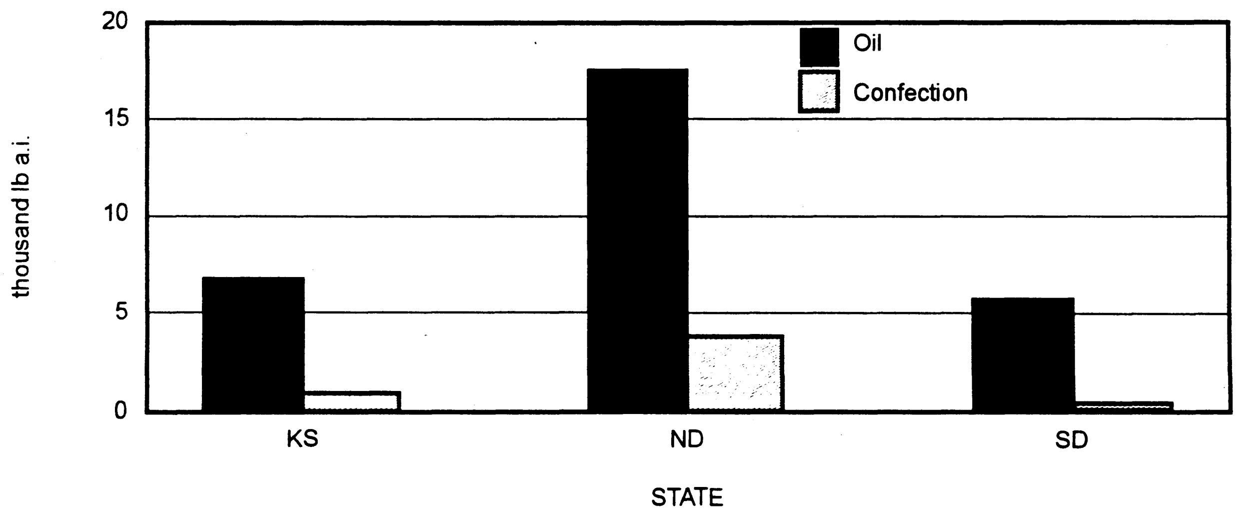
As a native plant to the United States, sunflower has a well-developed endemic insect fauna, with several species having the potential to cause economic loss (Charlet et al., 1987). A recent survey by Lamey (unpublished data) found that 9 percent of Minnesota growers, 14 percent of Kansas growers, and 41 percent of North Dakota growers ranked insects as their worst production problem. Because of this magnitude of insect pressure and the predominance of insects attacking the developing head and seeds, growers frequently turn to insecticides for crop protection.

Chlorpyrifos 4E and 15G are registered on sunflower for controlling eight insect pests. At-planting chlorpyrifos 4E broadcast and 15G banded over the row are labeled for cutworm control. Similarly, a rescue application of 2 to 3 pt per acre after emergence is labeled for cutworm infestations. Post-emergence foliar applications of 4E are labeled for control of sunflower beetle, stem weevils, sunflower moth, banded sunflower moth, woollybear, and/or seed weevils at rates of 1 to 1.5 pt per acre. A lower rate of 1 pt per acre is labeled for control of grasshoppers. More explicit instructions and precautions are listed on the respective labels.

PEST INFESTATION AND DAMAGE

Several insect pests that attack sunflower are listed below. Insects that attack the developing head, florets, and developing seeds are particularly well represented. Information on these insects, their life cycle, resulting damage, and management is reviewed for the Northern Plains States by McMullen (1985). In South Dakota, producers in 1990 listed the following insects as their most prevalent problem: seed weevils, (88.4 percent); stem weevils (55.8 percent); cutworms (42.3 percent); sunflower moth, *Homoeosoma electellum* (Hulst) (40.4 percent); grasshopper (30.8 percent); sunflower beetle, *Zygogramma exclamationis* (Fabricius) (17.3 percent); banded sunflower moth, *Cochylis hospes* Walsingham (13.5 percent); and wireworms (Elateridae) (13.5 percent) (Langner, 1991). Similarly, Lamey (1993) surveyed sunflower insect problems in 1991 in three States: Kansas, Minnesota, and North Dakota. In the Southern Plains, Kansas respondents reported problems primarily with the sunflower moth (50 percent); seed weevils (21 percent); and grasshoppers (5.5 percent). Minnesota growers encountered the following pests: seed weevils (31.6 percent); grasshoppers (13.6 percent);

Figure 14. Chlorpyrifos 4E Use on Sunflower, 1987-89 Average [Total oil = 29,520 lb a.i.; Total confection = 4,838 lb a.i.]



and stem weevils (6.8 percent). North Dakota growers reported similar pest problems: seed weevils (49.3 percent); grasshoppers (24.6 percent); and stem weevils (14.8 percent). The importance of the sunflower moth diminished in the more northerly States: Texas (100 percent) (Patrick, personal interview); Kansas (50 percent); Minnesota (1.5 percent); and North Dakota (1.0 percent). In each State, seed weevils were viewed as more of a problem by confection growers than by oilseed growers: Kansas (50 percent vs. 14.7 percent); Minnesota (61.4 percent vs. 24 percent); and North Dakota (58.6 percent vs. 49.3 percent).

PEST MANAGEMENT

Current Chemical Usage

Current insecticide usage on sunflower was relatively high during the 1987-89 survey period, but generally decreased from south to north among the five States. Insecticide use involving all of the sunflower types (oilseed and confection) averaged 100 percent in Texas, 92 percent in Kansas, 36 percent in North Dakota, 22 percent in South Dakota, and 20 percent in Minnesota for this survey period. To illustrate not only the importance of insects, but also the variation between years, a more recent survey by Lamey (1993) found Kansas growers treating 61 percent of the acreage, Minnesota growers treating 21 percent, and North Dakota growers treating 85.4 percent.

The likelihood of confection sunflowers receiving an insecticide application was generally higher than for oilseed sunflowers: Kansas (95 vs. 90 percent) and Minnesota (43 vs. 13 percent). Similarly, Lamey found confection/oilseed treatment rates of 164 percent vs. 51 percent (Kansas); 80 percent vs. 28 percent (Minnesota); and 216 percent vs. 90 percent (North Dakota). (Rates more than 100 percent indicate that more than one treatment occurred).

During the survey period, insecticide use for Kansas, Minnesota, and North and South Dakotas averaged 0.674 million acres (35.3 percent). However, only 0.06 million acres (3.3 percent) were treated with chlorpyrifos. Chlorpyrifos use was very low, accounting for only 8 percent of the total insecticide use on sunflower.

This proportion did not change appreciably between oilseed and confection sunflowers. The 4E formulation dominated chlorpyrifos use, with no State reporting 15G use.

Chemical Alternatives to Chlorpyrifos

Several pesticide alternatives to chlorpyrifos are registered for the insect pests appearing on the chlorpyrifos label (Table 27). Lamey (unpublished data) found the following use in 1991 in Kansas, Minnesota, and North Dakota among these alternatives: all parathions—58.1 percent (methyl parathion, 26.2 percent; ethyl parathion, 14.4 percent; 6-3 mixture, 17.4 percent); esfenvalerate—31.0 percent; Furadan—8.8 percent (4F, 4.2 percent; 15G, 4.6 percent); carbaryl—2.5 percent; and chlorpyrifos—1.4 percent.

Most respondents did not list any constraints to the use of alternative insecticides. No changes in yield or quality were anticipated with the loss of chlorpyrifos. Costs of alternatives were generally lower or comparable. For these reasons, respondents did not believe that the loss of chlorpyrifos would have much impact under the present situation. On the other hand, loss of these alternatives through reregistration, special reviews, or dropping of labels by the companies could greatly alter this viewpoint. Two respondents voiced concerns about loss of alternatives in the face of these uncertainties. In particular, one respondent noted that chlorpyrifos is one of few General Use pesticides labeled on sunflower in a market dominated by Restricted Use pesticides.

Table 27. Pest spectrum on labels of chlorpyrifos and alternative insecticides on sunflower.

Insecticide[b]	Insect[a]											
	CW	SBM	STW	SMG	TC	SB	GH	SMD	HCW	SSW	SM	BSM
chlorpyrifos	*	-	*	-	-	*	*	-	-	*	*	*
Bacillus thuringiensis	*	-	-	-	-	-	-	-	-	-	*	*
carbofuran	-	-	*	-	-	*	*	-	-	*	*	*
carbaryl	*	-	*	-	-	*	-	-	-	-	*	-
endosulfan	-	-	-	-	-	-	-	-	-	-	*	-
esfenvalerate	*	-	*	*	-	*	*	-	-	*	*	*
methidathion	-	-	*	*	-	-	-	*	-	*	*	*
methyl parathion	-	-	-	*	-	-	-	-	-	*	*	-
6-3 ethyl-methyl parathion	-	-	*	*	-	-	*	-	-	*	*	-
ethyl parathion	-	-	-	-	-	-	-	-	-	-	*	-

[a]Insect pests coded as follows: CW - cutworms, SBM - sunflower bud moth, STW - stem weevils (gray, black), SMG - sunflower maggot, TC - thistle caterpillar, SB - sunflower beetle, GH - grasshoppers, SMD - sunflower midge, HCW - head clipper weevil, SSW - sunflower seed weevils (spotted, red), SM - sunflower moth (head moth), BSM - banded sunflower moth.
[b]An asterisk (*) indicates one or more formulations or products with this active ingredient have the pest insect on the label. A dash (-) indicates no mention on the label.

Comparative Performance

Insecticide trials generally indicate comparable performance between chlorpyrifos and the more widely used products. Respondents indicated no change in yield expected with shifts to alternatives. Chlorpyrifos provides strong cutworm control, comparable to that of the pyrethroids.

Pesticide Resistance

There are no recorded cases of resistance to pesticides in sunflower insect pests. The continued registration of chlorpyrifos would allow for rotation of chemicals to delay resistance development.

Impact on Beneficial Insects

Little impact on pollinators or beneficial insects would be expected if chlorpyrifos registration were altered.

Integrated Pest Management

Because sunflower is a native crop attacked by a well-developed complex of insect pests, insecticides are viewed as an integral component of sunflower insect management. Crop monitoring is essential in determining if insecticides are needed for crop protection. Small differences in the timing of insecticide applications can lead to dramatic differences in pest control of head- and seed-attacking insects. A 1985 North Dakota survey found sunflower accounted for 42 percent of acreage scouted by crop consultants, but only 16 percent of the State's crop acreage. Cultural practices, such as the planting date, can be very important with some insects such as the sunflower midge, where delayed planting can dramatically reduce the level of infestation.

SUMMARY

Sunflower is grown primarily for oil and confection purposes on nearly 1.9 million acres across five States: North Dakota, South Dakota, Minnesota, Kansas, and Texas. As a native plant, sunflower is attacked by a complex of endemic insect pests, the most important to crop production being the seed- and head-feeding insects. In response to this threat (as well as the limited management alternatives that are available for controlling these pests), insecticide use is high. Kansas, Minnesota, and North and South Dakota report 0.674 million acres of sunflower production (35.3 percent of the total sunflower acreage is treated with some insecticide). Chlorpyrifos 4E and 15G are labeled for controlling eight sunflower insects. Use of chlorpyrifos is low (accounting for only 8 percent of the total insecticide use on sunflower (0.06 million acres). Because of this low usage, plus the availability of several efficacious alternatives that are competitively or lower priced than chlorpyrifos, there would be minimal impact on sunflower production if chlorpyrifos were removed from the market. Chlorpyrifos and carbaryl are the only insecticides registered on sunflower that are General Use insecticides.

Chlorpyrifos Use on Tobacco

Lee H. Townsend

INTRODUCTION

Tobacco is an important crop grown on approximately 680,000 acres in 21 States. This crop is concentrated east of the Mississippi river in the Southeastern United States. Tobacco grows in well-defined areas where soil and climatic characteristics produce crops with specific qualities. These qualities are sought by buyers in the industry and provide distinctive contributions to the development and manufacture of various tobacco products. Tobacco's annual value is estimated at more than $2 billion.

Based on the method of curing, the three basic classes of tobacco are flue-, air-, and fire-cured. Flue-cured tobacco is grown in North and South Carolina, Virginia, Georgia, Florida, and Alabama. Fire-cured tobacco is grown in Kentucky, Tennessee, and Virginia. Air-cured burley tobacco is produced in Kentucky, Tennessee, Virginia, North Carolina, Indiana, Ohio, West Virginia, Missouri, Maryland, and Pennsylvania. Cigar tobacco is grown in Pennsylvania, Ohio, Connecticut, Wisconsin, and Massachusetts. Perique tobacco is grown in Louisiana. More than 90 percent of U.S. tobacco production occurs in North Carolina, Kentucky, Tennessee, Virginia, South Carolina, Georgia, and Maryland.

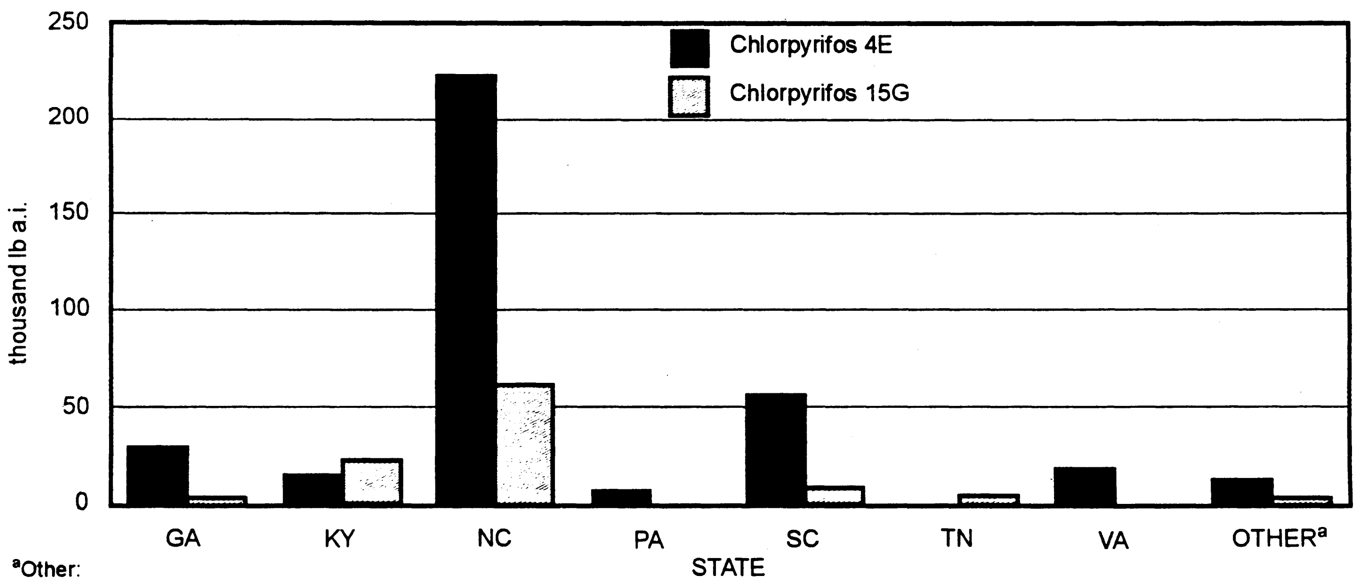
Chlorpyrifos 4E is registered as a preplant application to control several species of cutworm larvae, flea beetle, mole crickets, root maggots, and wireworms on tobacco. Chlorpyrifos 4E applications will also suppress movement of imported fire ants into treated fields. The recommended application is 2 to 3 lb a.i. per acre in at least 10 gallons of water, applied as a broadcast spray to soil and incorporated into the soil to a depth of 2 to 4 inches 1 week prior to transplanting.

In North Carolina, South Carolina, and Virginia, chlorpyrifos may be applied at 5 lb a.i. per acre for controlling low-to-moderate populations of root-knot nematodes. At 2 lb a.i. per acre, chlorpyrifos may be mixed with fenamiphos at the rate of 3 lb a.i. per acre for controlling moderate populations of root-knot nematodes. Chlorpyrifos is applied as a broadcast spray to soil surfaces 24 to 48 hours before bedding and transplanting, and is then immediately incorporated into soil to a depth of at least 4 inches.

Chlorpyrifos 15G is registered as a preplant treatment to control cutworms, flea beetle larvae, root maggots, and wireworms. Application of this chemical also suppresses movement of imported fire ants into treated fields. Granular formulations are applied at 2 to 3 lb a.i. per acre 1 week before transplanting, and are incorporated into the soil at a depth of 2 to 4 inches. One application of this pesticide is allowed per season.

For data on usage of chlorpyrifos 4E and 15G, see Figure 15.

Figure 15. Chlorpyrifos 4E and 15G Use on Tobacco, 1987-89 Average
[Total 4E = 362,062 lb a.i.; Total 15G = 89,942 lb a.i.]



[a]Other:
4E = FL,MD,TN
15G = FL,MD

PEST INFESTATION AND DAMAGE

Primary Pests

Several species of wireworms, especially *Melanotus* and *Conoderus* spp., attack tobacco. The larval stage lives from one to several years in the soil and feeds on plant roots, seeds, and organic matter (Akehurst, 1969). Wireworms are common pests when tobacco is planted as a rotational crop in sequence with small grains or sod (Gooden, 1990; Sims, 1990). Wireworm injury in tobacco is most severe where tobacco is rotated out of sod (Jewett, 1940). However, crop rotation is still recommended to alleviate potential disease buildup and nutrient imbalance, as well as to improve soil structure.

Wireworms attack tobacco plants soon after the plants are transplanted. Wilted plants in fields are the first indication of a problem. There are no effective rescue treatments. If a soil insecticide is used, it must be applied and incorporated into the soil 1 week prior to transplanting. The decision to use a preventive soil insecticide application is usually based on a prior history of wireworm problems in the field or as a routine preventive measure.

Secondary Pests

Tobacco flea beetle, *Epitrix hirtipennis* (Melsheimer), is an important early season pest in virtually every tobacco field. Scars on tobacco roots, resulting from flea beetle larval feeding, allow the establishment of secondary plant pathogens and decrease the growth potential of infested plants. Semtner (1984) observed that feeding by both larvae and adults reduced yield, plant growth, and stand uniformity. He also reported that relatively low populations (5 beetles per plant during the first 3 weeks after transplant) can significantly reduce yield by 18 to 38 percent.

The black cutworm, *Agrotis ipsilon* (Hufnagel), is a common and potentially destructive pest of tobacco (Crumb, 1929). Black cutworm larvae feed on tobacco plants by severing the stem, causing irrevocable injury to the plant. This pest is present in the early spring, feeding on a wide variety of plants. Sherrod et al. (1979) presented two important concepts in field biology regarding the black cutworm in Illinois. First, infestations of this insect originate from eggs laid in the spring before the crop is planted. Second, agronomic practices that encourage the establishment of weeds (especially winter annual and perennial weeds) increase the potential for the presence of this cutworm. Johnson et al. (1984) demonstrated that tillage, rotation, and weed management factors significantly affected black cutworm infestations and subsequent damage.

Four species of root-knot nematodes (Lucas, 1975) are important pests of flue-cured tobacco in the United States: *Meloidgyne incognita* (Kofoid and White); *Meloidgyne hapala*, Chitwood; *Meloidgyne arenaria* (Neal) Chitwood; and *M. javonica* (Treub) Chitwood. *M. Incognita* is the most important species in North Carolina and Virginia.

PEST MANAGEMENT

Current Chemical Usage

Florida, Georgia, North Carolina, South Carolina, and Virginia—These States grow primarily flue-cured tobacco. Granular insecticides are rarely used in tobacco production in these States. Highest use of these insecticides (8 percent of the acreage) was reported from North Carolina, the State with the largest tobacco acreage. This particular formulation was used on approximately 1 percent or less of the remaining acreage in the Southeast. Chlorpyrifos 4E is widely used in all States. Ethoprop and acephate are alternatives, with ethoprop the preferred alternative.

Kentucky and Tennessee—Burley tobacco is the main tobacco crop grown in Kentucky and Tennessee. Both States reported that a low percentage of tobacco acreage receives preventive wireworm or cutworm treatments (approximately 3 to 7 percent). The amount of pesticides used is evenly divided between liquid and granular formulations.

Chemical Alternatives to Chlorpyrifos

Acephate is labeled for cutworm control as a transplant water application at 0.75 lb a.i. per acre. It is also used against cutworms at the same rate as a foliar spray after plants have been set in the field.

Disulfoton 15G is registered to aid in the control of the southern potato wireworm, *Conoderus falli* Lane. Granular and liquid formulations of ethoprop (6 to 8 lb a.i. per acre) and disulfoton (3 to 4 lb a.i. per acre) combinations are labeled for controlling root-knot nematodes and wireworms.

Wireworms pose a significant insect control challenge for tobacco growers because treatments must be preventive, with no option for remedial applications. Insecticide alternatives to chlorpyrifos are becoming scarce. The registration of carbofuran, the only insecticide/nematicide alternative, has been canceled by the manufacturer (FMC Corp), and usage of this pesticide is being phased out. The CIBA-Geigy Corporation, the basic producer of diazinon, has indicated that it will not support the continued registration of diazinon on tobacco. This leaves only disulfoton, ethoprop, and fonofos as alternatives to chlorpyrifos for tobacco.

Acephate may be used as a foliar spray for cutworm infestations. Baits containing carbaryl or trichlorfon are also registered alternatives to chlorpyrifos for cutworm control. Because cutworm infestations tend to be sporadic, the pesticide recommendations in most States advise the use of rescue treatments based on field scouting information rather than using preventive planting-time applications.

There are limited trial data available on the performance of chlorpyrifos and alternative insecticides for controlling soil pests that attack tobacco. Southern (1984a) demonstrated that carbofuran, chlorpyrifos, diazinon, disulfoton, ethoprop, and fonofos all gave statistically significant protection from the tobacco wireworm, *Conoderus vespertinus* (Fabricius), as compared to untreated plots. Mean yield and quality indices, however, were not significantly affected by the treatment. A 1983 trial found that carbofuran, chlorpyrifos, and diazinon protected tobacco transplants from injury by wireworms (Southern, 1984b). There were no statistical differences in injury ratings among treatments, nor were there significant yield differences. Lempert and Stephensen (1987) reported comparable performance of chlorpyrifos, carbofuran, and ethoprop in reducing injury from wireworms, *Conoderus* spp., in flue-cured tobacco. Townsend and Jones (1984) demonstrated a reduction in the emergence of tobacco flea beetle adults from tobacco plots receiving an application of chlorpyrifos and carbofuran. No yield effect was reported.

Nonchemical Alternatives

Jewett (1940) investigated several nonchemical approaches to wireworm control, including: fall plowing; reducing plant spacing within rows; increasing the diameter of transplants; and delaying planting dates. He found that increased transplant stem diameter resulted in better survival of damaged plants and that early-set tobacco was more heavily damaged than late-set tobacco. The use of transplants of appropriate stem diameter is recognized by most growers as important in general, but the advantage in terms of wireworm attack in particular may not be recognized. Delaying planting long enough to reduce losses from wireworm infestations may be less widely applicable. Determination of such dates would be difficult, and the delay may result in intensifying other problems, such as losses to viral diseases.

Other nonchemical alternatives include the use of resistant cultivars and crop rotation to reduce nematode damage. Johnson et al. (1984) documented that proper weed control may reduce the incidence of cutworm damage.

Pesticide Resistance

There are no recent reports addressing the pesticide resistance issue with regard to target pests considered in this analysis.

Impact on Beneficial Insects

The major potential for detrimental effects on beneficial insects is in the reduction of insect populations such as ground beetles. These beetles are predacious on agricultural pests, including soil insects (Frank, 1971; Best and Beegle, 1977) and weed seeds (Lund and Turpin, 1977).

Field studies on the toxicity of soil-applied pesticides to the spined stilt bug, *Jalysus wickhami* Van Duzee, demonstrated that nonsystemic insecticides, including chlorpyrifos, did not significantly reduce survival of this beneficial insect on tobacco plants (Jackson and Lam, 1989).

Integrated Pest Management

In general, sound integrated pest management decisions require accurate identification of the pests involved, assessment of population levels, and the use of the most current economic threshold or treatment guidelines. Baiting and soil sampling techniques already available may be used to collect information on the types and numbers of wireworms, cutworms, or nematodes present in a field. However, some important species may not respond to baits or traps, or may lack reliable identification characteristics to separate them from less destructive species. Use of baiting techniques prior to or just after planting may be useful for cutworm management in corn (Story and Keaster, 1982). Most States have information on how to scout fields for cutworms, and have a recommended treatment threshold. Because cutworm outbreaks tend to be sporadic, Extension entomologists recommend scouting fields for symptoms of cutworm infestations and applying a rescue treatment, if necessary.

FUTURE PEST MANAGEMENT OPTIONS

With the loss of registration of carbofuran and diazinon on tobacco, options for chemical control of tobacco pests have decreased. In addition, no new products appear to be near registration.

Nonchemical control options that involve crop rotation sequences to minimize buildup of damaging populations of soil pests are the most logical alternatives; however, additional research is needed to properly evaluate these options. Selection of cover crops to minimize pest problems, and tillage practices to reduce oviposition of pests such as wireworms or cutworms, may also have some applications.

SUMMARY

Tobacco is a high-value cash crop. Most States reported that an average of less than 10 percent of the tobacco acreage received an insecticidal treatment, although in the major tobacco-growing States (e.g., North Carolina), as much as 62 percent of the acreage is treated with a soil insecticide. Removal of chlorpyrifos from the marketplace would be a significant loss to the tobacco industry, leaving only two or three chemical alternatives for pest control. Chlorpyrifos 15G and 4E are General Use pesticides. Alternatives to chlorpyrifos are ethoprop, fonofos, and disulfoton, which are Restricted Use insecticides.

Chlorpyrifos Use on Wheat

Gary L. Hein and John F. Witkowski

INTRODUCTION

An average of 69 million acres of wheat was planted each year in the United States from 1987 to 1989. In 1989, the 10 leading States in production were Kansas, North Dakota, Oklahoma, Washington, Montana, Minnesota, Texas, South Dakota, Idaho, and Illinois.

Over the last 5 years, the Russian wheat aphid has emerged as the most serious pest attacking wheat in the arid, wheat-growing regions of the Western United States (Hein et al., 1990). Foliar insecticides are the primary method for controlling this pest.

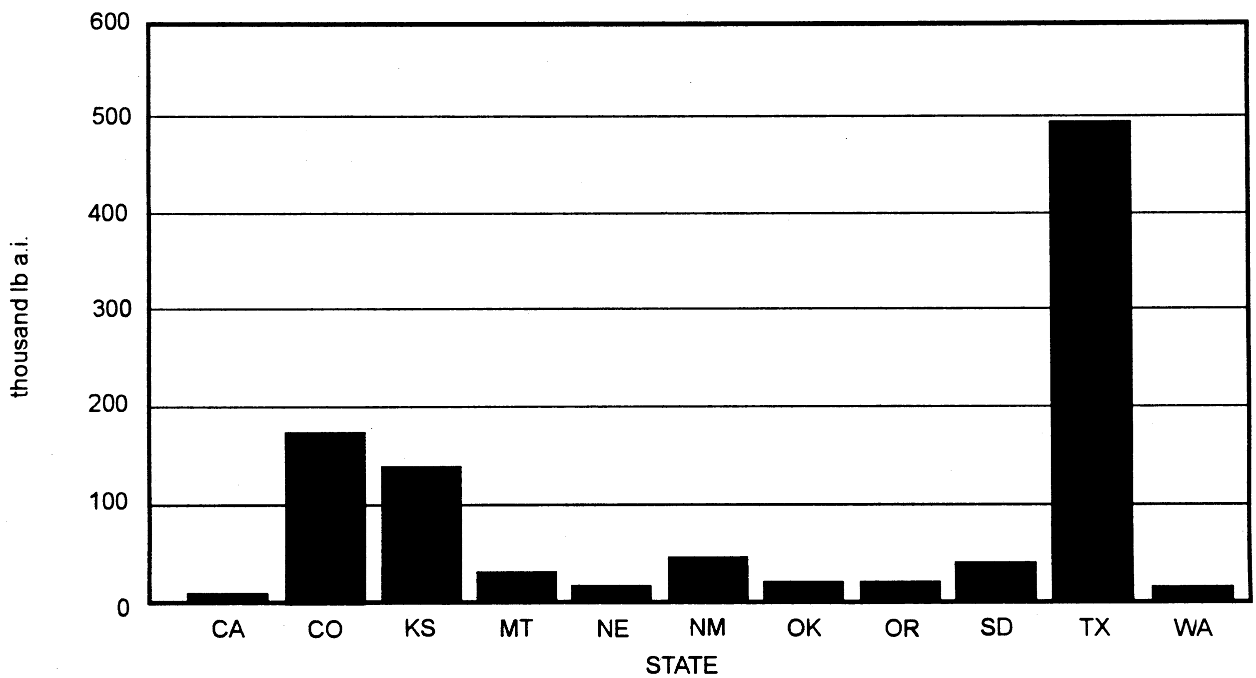
Chlorpyrifos 4E currently does not have a Federal label for aerial or ground use on wheat in the United States. Since 1988, the Environmental Protection Agency has granted specific exemptions to certain States for the use of chlorpyrifos 4E on wheat to control Russian wheat aphid under the provisions of Section 18 of the Federal Insecticide, Fungicide, and Rodenticide Act, as amended. Those States included: California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, Oklahoma, Oregon, South Dakota, Texas, Utah, and Washington. Chlorpyrifos 4E has also been used for army cutworm control via crisis and Section 18 registrations in some States. For usage details, see Figure 16.

PEST INFESTATION AND DAMAGE

The Russian wheat aphid, *Diuraphis noxia* (Mordvilko), was found for the first time in the United States near Muleshoe, Texas in spring 1986. Since that time it has spread rapidly north into Canada and west to the Pacific (Stoetzel, 1987). The current range of this aphid includes all States in regions to the west of the 100th meridian. About half of the acres of wheat grown in the United States occur within the distribution of the wheat aphid (Hein et al., 1990). Severe localized outbreaks of infestations have occurred throughout the Russian wheat aphid range and are concentrated in Colorado and surrounding States in the Great Plains and also in Washington and Idaho. The economic losses attributed to this pest totaled more than a quarter of a billion dollars from 1987 through 1989 (Hein et al., 1990).

The Russian wheat aphid reproduces continuously throughout the year as temperatures permit. Studies compared the increased cold tolerance of the Russian wheat aphid with respect to the greenbug *Schizaphis graminum* (Rondani) (Harvey and Martin, 1988). The Russian wheat aphid is able to overwinter as far north as Nebraska and Wyoming, and perhaps in some areas of Montana. This insect spends most of the year, fall through spring, primarily on winter wheat. However, once the winter wheat begins to dry down, the

Figure 16. Chlorpyrifos 4E Use on Wheat, 1987-89 Average[a]
[Total = 976,531 lb a.i.]



[a]Exemption labeling—Russian Wheat Aphid

aphids move to alternate hosts in the surrounding landscape. Numerous native and introduced alternate hosts have been identified for the Russian wheat aphid (Kindler and Springer, 1989). In the fall, aphids migrate to recently planted winter wheat fields.

The Russian wheat aphid is found within the curled upper leaves of wheat tillers. Aphid colonization results in discoloration of leaves and tight leaf curling. If infestation occurs prior to head formation, the awns of the heads may become trapped and normal head development will be distorted. Russian wheat aphid continues to feed during the head development stages, moving into the head and feeding directly on the awns and berries. Thomas and Butts (1990) found that fall feeding by these insects will result in reduced winter hardiness of wheat. Early-season infestations result in reduced vegetative growth. Archer and Bynum (1989) found approximately 0.5 percent yield reduction for each 1 percent infested tiller present during spring infestations of winter wheat. Infestations during the heading stages resulted in reduced weight per seed (Gray et al., 1990). Yield reduction attributed to Russian wheat aphid in the Western United States during 1988-89 was responsible for economic losses of approximately $60 million on winter and spring wheat (Hein et al., 1990).

Chlorpyrifos has been used for Russian wheat aphid control exclusively at 0.50 lb a.i. per acre. The chlorpyrifos label for use in Nebraska lists minimum water volume as 20 gallons per acre (ground application) and 2 gallons per acre (aerial application). Chlorpyrifos treatments are applied either in the fall or spring. Occurrence of significant populations of Russian wheat aphid requiring treatment varies in different areas. In Northwest United States, significant infestations are more likely to occur in the fall on seedling wheat. In the Great Plains, major infestations are more likely to occur in the spring through the early heading stages.

PEST MANAGEMENT

Current Chemical Usage

Russian wheat aphid is the primary target pest that attacks wheat crops in all of the States that have been granted Section 18 uses. Current management of the Russian Wheat aphid is almost exclusively restricted to the use of insecticides. However, Nebraska and South Dakota reported limited chlorpyrifos usage for controlling the army cutworm, *Euxoa auxiliaris* (Grote). The percentage of acres treated with chlorpyrifos for controlling Russian wheat aphid ranged from zero in several States to 15 percent in New Mexico and Texas. Because of the increased number of Section 18 exemptions granted in the last 3 years, chlorpyrifos usage has increased dramatically. However, the total acres treated for these aphids has remained relatively stable (Hein et al., 1990). Survey respondents projected that the impact of losing chlorpyrifos registration would range from a 0 to 6 percent reduction in wheat yield.

Chemical Alternatives to Chlorpyrifos

There are few alternative pesticides available for controlling aphids. These alternatives include disulfoton, dimethoate, malathion, and parathion. Because the Russian wheat aphid is found within the tightly curled leaves of plants, control of this insect is difficult. Efficacy is the primary criterion in determining options for control. Disulfoton has proven to be the only registered alternative insecticide that performs consistently for Russian wheat aphid control. However, this chemical is a Restricted Use material and cannot be safely applied by ground equipment. In addition, the disulfoton label prohibits grazing in treated fields. This restriction eliminates disulfoton as an option for a large number of wheat producers.

Comparative Performance

Since the Russian wheat aphid is a "new" pest, insecticide use is the only viable management option currently available for controlling aphid infestations. Small-plot field trials have shown alternative chemicals to be reasonably efficacious. However, these alternatives, except for disulfuton, are not consistently effective on large-scale usages. Systemic insecticides, such as disulfoton and dimethoate, are possible candidates for control. However, because of the relationship between Russian wheat aphid infestations and drought stress, the performance of systemics may vary because these chemicals rely on the plants to transport them to the proper sites. Of these two insecticides, only disulfoton has proven consistently effective.

Nonchemical Alternatives

There are a series of cultural recommendations applicable in some regions that may help reduce the potential for Russian wheat aphid infestations affecting wheat. These recommendations include adjusting planting dates by delaying planting in the fall and implementing early planting for spring wheat; controlling volunteer wheat in adjacent areas; and maintaining maximum plant vigor by proper fertility, optimum seed quality, and reduced weed competition (Hein et al., 1989; Peairs, 1989). Numerous natural enemies feed on the Russian wheat aphid, including several Coccinelid species, syrphid larvae, and several species of parasitic wasps (Hymenoptera). However, these natural enemies do not become major controlling factors until aphid populations become extreme. At the present time, all adapted varieties of wheat are susceptible to Russian wheat aphid damage (Webster et al., 1987; Quick et al., 1991).

Pesticide Resistance

Russian wheat aphid resistance has been identified, and estimates for release of adapted resistant varieties range from mid- to late 1990's (Quick et al., 1991; Nkongola et al., 1990).

The loss of registration for chlorpyrifos would leave disulfoton to be used in areas where livestock grazing restrictions on disulfoton are acceptable. The primary reliance on disulfoton for pest control would increase the rate of resistance development to this chemical.

Integrated Pest Management

Because various adapted wheat varieties are highly susceptible to infestations of extremely low populations of Russian wheat aphid, current Integrated Pest Management options are limited. Economic thresholds at this time are so low that insecticidal treatments are recommended before noninsecticidal alternatives could be expected to impact the Russian wheat aphid population (Archer and Bynum, 1989; Peairs, 1989). Significant improvements in the IPM strategies for controlling Russian wheat aphid may occur when resistant varieties of wheat are made available to wheat growers. The current source of resistance has shown tolerance to Russian wheat aphid and this will result in a raising of the current low economic threshold. This will also allow a certain level of "background" Russian wheat aphid infestations to be present in these wheat fields. Extensive efforts are being made by USDA/APHIS personnel to locate and introduce exotic natural enemies of the Russian wheat aphid into the United States. If effective natural enemies of the Russian wheat aphid are identified and made available, these enemies could supplement control of the Russian wheat aphid.

SUMMARY

The Russian wheat aphid presents a serious pest problem for wheat growers in this country. Foliar insecticides have been used to control this pest. Although there are several insecticidal alternatives, only chlorpyrifos and disulfoton have proven to be consistently effective against this insect. Disulfoton has some serious limitations for broad use: it is a Restricted Use chemical; it cannot be safely applied with ground equipment; and its label prohibits grazing in treated fields. Because of these and other reasons documented in the text, the removal of chlorpyrifos from the market would have a significant, negative impact on wheat production in the United States.

Chlorpyrifos Use on Apple

Dennis D. Kopp

INTRODUCTION

Commercial apple production uses more pesticides per acre than most other major U.S. crops (Croft, 1983). This high use rate has led the general public, researchers, and regulatory agencies to investigate the efficacy of more selective active ingredients, the development of better formulations and application methods, and the judicious use of current products.

Chlorpyrifos is an important and widely used insecticide in apple production. For usage details, see Figure 17. Chlorpyrifos 50W and 4E are registered for use on apple to control various insect pests. In the United States, apple production was reported on 36,718 farms (U.S. Department of Commerce, 1987). From 1987 to 1989, 462,000 bearing acres produced an average of more than 9 billion lb of apple annually in the United States.

Twenty-eight species of arthropods are listed on the chlorpyrifos 50W label. Chlorpyrifos label recommendations for rates and frequency of application vary with pest and formulation. The post-treatment harvest interval for orchard usage on apples is 28 days.

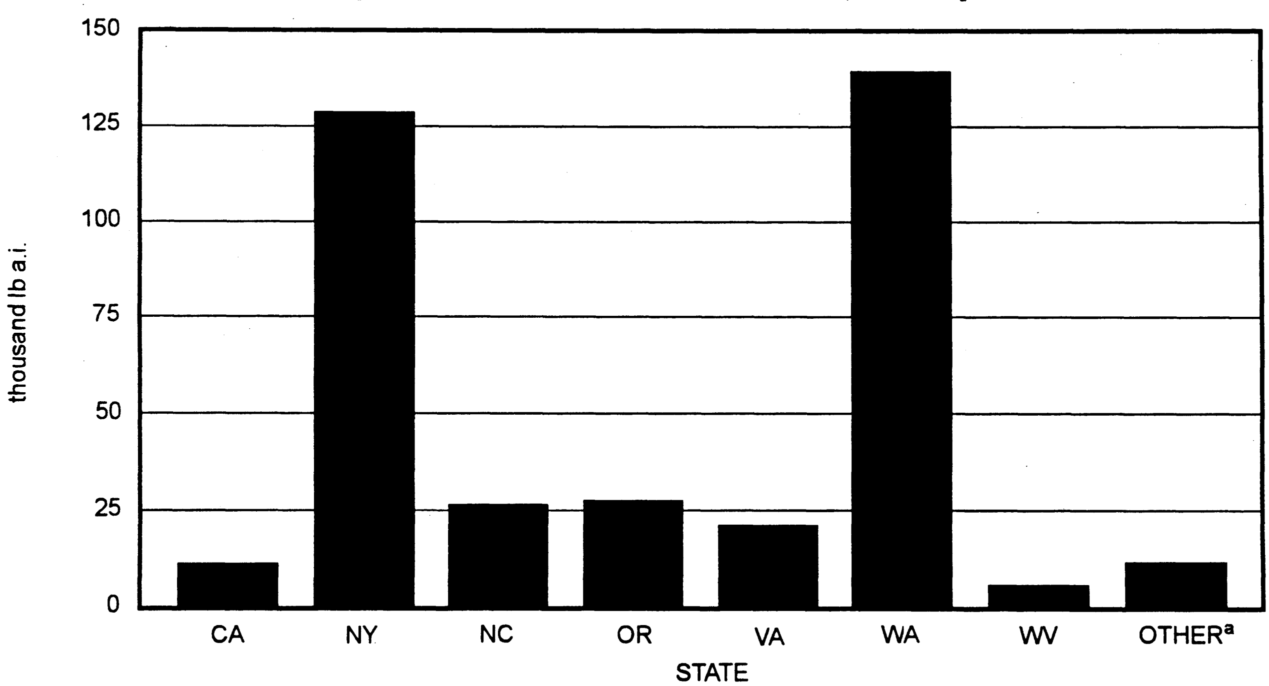
Chlorpyrifos 4E is registered for use during the dormant or delayed-dormant stages of apple tree development. Dormant or delayed-dormant sprays are often made in combination with petroleum oil spray. Chlorpyrifos 4E provides effective control of the rosy apple aphid, San Jose scale, *Lygus* spp., pandemis leafroller, and climbing cutworms. The label states that one application, only at the rate of 0.25-0.50 lb a.i. per 100 gal water, may be applied per season at the rate of 200 to 600 gal finished spray per acre.

In the accumulation of pesticide usage data from State scientists, the surveyors were unable to obtain information from three major apple-producing States. These States were Michigan, with more than 50,000 acres; Pennsylvania, with more than 25,000 acres; and California, with more than 23,000 acres. It was possible to extrapolate some data from a diazinon questionnaire from California; however, this missing information weakens the evaluation of the impact of chlorpyrifos on the Nation's apple production.

PEST INFESTATION AND DAMAGE

A cadre of apple arthropod pests can be found throughout the major apple production regions of North America. However, a regionality exists in that certain apple pests are predominant in some regions and secondary in importance in other regions. In Washington and other Western States, more pesticide applications are made to control codling moth, *Cydia pomonella* (Linnaeus), than any other apple pest. In New York, both the codling moth and the plum curculio, *Conotrachelus nenuphar* (Herbst), have the potential to become the

Figure 17. Chlorpyrifos 4E and 50WP Use on Apple, 1987-89 Average
[Total 4E = 178,988 lb a.i.; Total 50WP = 194,544 lb a.i.]



[a]Other = DE,GA,NH,NJ,WI

most severe apple pests; however, populations of these insects are held below damaging levels by controls directed at other pests (A. Agnello, 1993, personal communication).

In Washington State, the top five insects that impact apple production are codling moth; leafrollers; leafminers; *Lygus* bugs, *Campylamma*; and aphids (E. Beers, 1993, personal communication). Additional pests of importance to Washington State apple production are the apple rust mite, *Aculus schlechtendali* (Nalepa); European red mite, *Panonychus ulmi* (Koch); white apple leafhopper, *Typhlocyba pomaria* McAtee; and the San Jose scale *Quadraspidiotus perniciosus* (Comstock). Reviews of the biology, life history, and management options of the major Western apple pests are presented in Williams (1991).

In California, the codling moth and San Jose scale are the two pests of major importance. The impact of these two arthropods dwarfs the impact of other pests in this State in comparison (F. Yoshikawa, 1993, personal communication).

In New York, the plum curculio and codling moth are maintained in secondary pest status due to treatment for the following pests, listed in sequence of importance: leafrollers; European red mite; apple maggot, *Rhagoletis pomonella* (Walsh); leafminers; and rosy apple aphid, *Dysaphis plantaginea* (Passerini) (Agnello et al., 1992). Other pests can be locally important to apple production, depending on environmental conditions during any one season or on the microclimate of any particular orchard.

In Pennsylvania, the rosy apple aphid has been a pest since the 19th century (Travis et al., 1989). The tufted apple bud moth, *Platynota idaeusalis* (Walker), is the most serious direct pest (attacking the developing fruit) of apple in the five-State Cumberland-Shenandoah region of the Eastern United States. Losses during the mid-1980's due to this one pest were estimated by Travis et al. (1989) at $4 million.

In other growing regions, such as Michigan, Wisconsin, North Carolina, and Georgia, there will be different combinations of the same pome fruit pests (depending on the unique environmental parameters and on the particular season of each of these regions).

PEST MANAGEMENT

Current Chemical Usage

In Delaware, Georgia, New Hampshire, New Jersey, New York, and North Carolina, the NAPIAP survey data indicate that chlorpyrifos 4E and 50W are the principal insecticides used for apple pest control. In Virginia and West Virginia, azinphos-methyl, methyl parathion, and esfenvalerate are the pesticides most frequently selected for apple pest control. In Washington and Oregon, endosulfan, chlorpyrifos 4E, and ethyl parathion are the major dormant spray insecticides used to control scales, aphids, mites, and leafrollers (Beers and Brunner, 1991). In the Western growing regions, azinphos-methyl and phosphamidon are the major insecticides used during the production season.

Chemical Alternatives to Chlorpyrifos

The following insecticides are alternatives for one or more of the pests chlorpyrifos is presently used to control: azinphos-methyl, carbaryl, diazinon, dimethoate, endosulfan, ethion, fenvalerate, malathion, phosmet, methoxychlor, methyl parathion, methomyl, permethrin, and superior oil. Many of these alternatives have label restrictions that narrow their potential usage more than chlorpyrifos, and several of these insecticides have demonstrated phytotoxicity on apple (Agnello, et al., 1992), which further restricts their usefulness as replacements for chlorpyrifos.

Another important factor related to an insecticide's usefulness in apple pest management is the post-treatment harvest interval. When using chlorpyrifos on apple, a 28-day interval is required between application and harvest. This 28-day interval is longer than that for most alternatives to chlorpyrifos, and is a constraint to the selection of chlorpyrifos for use as a late cover spray in apple orchards.

Comparative Performance

The comparative performance of chlorpyrifos to registered alternatives for each of the major insect and mite pests is listed in tabular format in Walqenbach et al. (1993). Performance rankings of pesticides are available in a number of IPM publications and are important considerations in providing production information to apple growers. The formulation of pesticide performance rankings are based on regional research trial data and product performance experiences witnessed by the author scientists of apple management publications. In insecticide and acaricide tests from 1987 to 1992, numerous trials contributed to the knowledge base of how well chlorpyrifos performs in controlling various insect and mite pests on apples. The performance of chlorpyrifos has been evaluated in all major apple-growing regions in the United States. The following chlorpyrifos/apple pest control performance articles have appeared in the "Insecticide and Acaricide Tests," 1987, vol. 12:1-55, 10 references; 1988, vol. 13:1-44, 8 references; 1989, vol. 14:1-45, 11 references; 1990, vol. 15:1-41, 8 references; 1991, vol. 16:1-22, 7 references; and 1992, vol. 17:1-43, 19 references. The following comparative performance statements are based on these data and other cited publications.

In comparative performance trials, chlorpyrifos was ranked as very effective in controlling scale insects by Walqenbach et al. (1993), Howitt (1989), Weires (1979), Weires and Alm (1979, 1980), and Weires and Lawson (1988). Methidathion and superior oil are also listed as very effective (Walqenbach et al., 1993), and both of these products are frequently used as alternatives to, or in combinations with, chlorpyrifos for scale control.

Other pests that chlorpyrifos has proven to be very effective in controlling are: codling moth (Walqenbach et al., 1993; Weires and Alm, 1979; Weires and Lawson, 1987, 1988); apple maggot (Walqenbach et al., 1993; Howitt, 1989; Weires and Alm, 1979; Weires and Lawson, 1987); plum curculio (Walqenbach et al., 1993; Weires and Alm, 1979; Weires and

Lawson, 1987, 1988); leafrollers (Walqenbach et al., 1993; Howitt, 1989; Weires and Alm, 1979; Weires and Lawson, 1987); and oriental fruit moth, *Grapholita molesta* (Busck) (Walqenbach et al., 1993; Weires and Alm, 1979).

Other insecticides that provided comparable control to chlorpyrifos for codling moth, apple maggot, plum curculio, oriental fruit moth, and leafrollers were azinophos-methyl, carbaryl, methomyl, methyl parathion, and phosmet (Walqenbach et al., 1993).

For aphids, chlorpyrifos has provided effective but inconsistent control in numerous trials. However, chlorpyrifos has often been outperformed by dimethoate, endosulfan, and methomyl (Walqenbach et al., 1993; Hull and Starner, 1983; Weires and Lawson, 1987, 1988).

The performance of chlorpyrifos for mite control has been inconsistent and was surpassed by dicofol, dimethoate, endosulfan, formetanate, hexakis, methomyl, methyl parathion (Penncap M), and propargite (Walqenbach et al., 1993). Because chlorpyrifos is not strongly acaricidal, a benefit of this pesticide is that its usage causes minimal population disruptions of beneficial mites.

Pesticide Resistance

The resistance of apple arthropod pests to pesticides is presently not a major production problem in orchard pest management, but is a major concern in IPM programs. The loss of pesticides due to resistance development presents a continual challenge to growers, scientists, and government regulators (Dover and Croft, 1984).

Organophosphate resistance is beginning to develop in the codling moth and the white apple leafhopper. Travis et al. (1989) report resistance to commonly used organic phosphate insecticides in the spotted tentiform leafminer, *Phyllonorycter blancardella* (Fabricius). Proper implementation of IPM techniques takes into account the ever-present potential for the development of resistance to frequently used pesticides. Rotation of insecticides among products with different modes of action, correct timing of insecticide applications, and selection of appropriate application rates all delay the development of resistance and prolong the usefulness of present apple pest management pesticides. Where resistance has been identified, appropriate and alternative control options may be utilized, as discussed by Agnello et al. (1992).

Kazmierczak et al. (1993) consider the economic consequences of resistance in an Eastern U.S. apple production system. Their model predicts a $1.91 billion present-value loss in economic benefits over a 25-year period if chlorpyrifos is discontinued.

Impact on Beneficial Insects

Apple set is heavily dependent on pollination by honey bees; therefore, the spraying of any insecticides during bloom is not recommended. Application of insecticide during the bloom period of apple causes bee kills. Bee protection is important throughout the season. The management of weeds, which grow in the orchard floor and attract honey bees, is essential in preventing unintentional killing of bees when orchards are being treated with an insecticide.

The protection of predaceous insects, mites, and other natural enemies of orchard pests is another important consideration in the timing and selection of pest management options. The searching behavior of effective arthropod predators increases the susceptibility of these arthropods to insecticide toxicity. Thorough coverage of any insecticide, including chlorpyrifos, will have a negative impact on predaceous arthropod populations (Agnello, et al., 1992). Pesticide application timing and product selection are important factors in reducing the impact of insecticide spraying on populations of beneficials.

Although several pyrethroids are registered for controlling aphids and plant bugs on apple and other orchard crops, producers are encouraged to use these chemicals infrequently. Often, an outbreak of mite populations will occur following pyrethroid usage. Mite population outbreaks may be caused by the reduction of the populations of natural enemies of phytophagous mites and the rapid increase of mite populations due to their inherent reproductive ability (i.e., once they have escaped the population reduction pressure of their natural enemies).

Integrated Pest Management

Apple lends itself to the implementation of IPM practices because of the orchards' stable arbor environment and diverse habitats. In addition, the high cash value of the grower's initial orchard investment and the high potential for per-acre dollar return on this investment makes selection of pest management a wise choice. Apple is one of the pioneer commodities where IPM has been documented as a viable, biologically sound, and profitable alternative to calendar spraying. All major apple-producing States have developed, implemented, and continued to support apple IPM programs through the efforts of Extension and research scientists within the Land Grant University System. The following publications are examples of literature that describes IPM programs: Croft, 1983 (for the United States in general); Agnello, et al., 1991 (New York); Rock, 1976 (North Carolina); and Williams, 1991 (Washington).

SUMMARY

Chlorpyrifos 4E and 50W are important and effective pest management tools in the multibillion dollar U.S. apple industry. Chlorpyrifos has broad usage in apple production nationally. The 4E formulation is used most frequently as a dormant spray, and the 50W formulation is used to control pests during the growing season. The 28-day interval between treatment and harvest is a constraint to the use of chlorpyrifos for late-season cover sprays. Additionally, chlorpyrifos is an important part of integrated pest management programs because it offers effective pest control in a pesticide rotation sequence.

Chlorpyrifos Use on Citrus

J. Victor French and John E. Fucik

INTRODUCTION

Chlorpyrifos is used for arthropod pest control on citrus in Arizona, California, Florida, Louisiana, and Texas. A total of 857,000 acres of citrus are planted in the United States. Chlorpyrifos is generally sprayed on trees for hemopteran pests, such as armored scale and unarmored scale, mealybugs, aphids, and whiteflies. Both liquid and granular chlorpyrifos formulations are very important for ant control in both bearing and nonbearing citrus orchards.

Chlorpyrifos was federally registered for use against on-tree citrus pests on July l9, 1982, and for ant control in citrus on September 9, 1985. For usage details, see Figure 18. Chlorpyrifos 4E liquid is used against the following insects: California red scale; Florida red scale; chaff scale; purple scale; snow scale; brown soft scale; and black scale. Chlorpyrifos 4E liquid is also used to control citrus thrips; citrus mealybug; green citrus aphid; citrus whitefly; katydids; citrus rust mite; cutworms; fruittree leafroller; orange tortrix; western tussock moth; and orangedog.

Chlorpyrifos 15G granular and chlorpyrifos 4E are insecticides used to control various ant species, including: red imported fire ant; Argentine ant; Texas leafcutting ant; harvester ant; southern fire ant; and tropical fire ant.

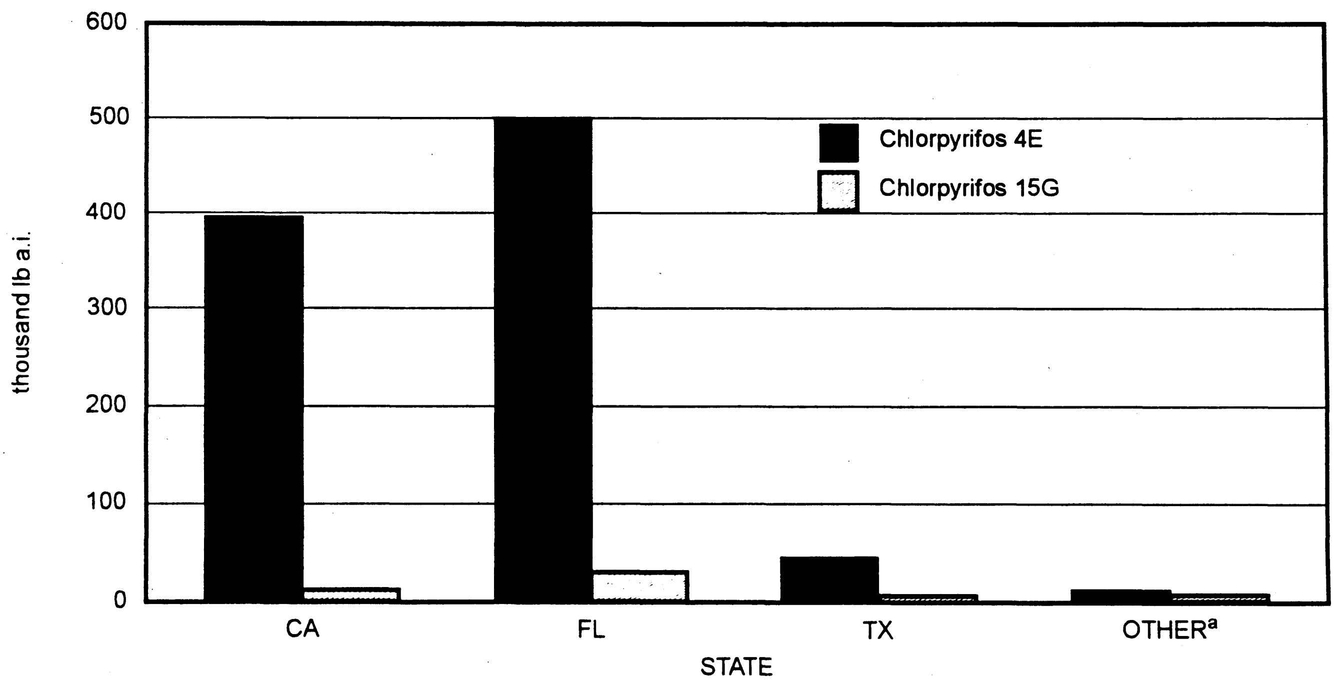
PEST INFESTATION AND DAMAGE

Primary Pests

The most important use of chlorpyrifos is for controlling armored scale insects (Diaspididae). These insects remove cell contents, thereby disrupting carbohydrate metabolism and translocation. Heavy infestations of these insects result in defoliation and twig and limb dieback and can even kill young trees. Uncontrolled California red scale, *Aonidiella aurantii* (Maskell), found on mature trees, often results in fruit yield reductions of 20 percent in some seasons (J.V. French, Texas A&I University, unpublished data). For fresh grapefruit, 50 or more settled scale per fruit can reduce grade to No. 2 or juice. In California, navel oranges are downgraded in the packinghouse when infested with 10 or more live or dead red scale (Walker et al., 1989).

Climate, beneficial insect complexes, and dominant citrus varieties cause the incidence and severity of scale species to

Figure 18. Chlorpyrifos 4E and 15G Use on Citrus, 1987-89 Average
[Total 4E = 955,009 lb a.i.; Total 15G = 48,568 lb a.i.]



[a]Other = AZ,LA

vary considerably in different areas. The most important scale species by State are California red scale in California and Arizona; California red scale and chaff scale, *Parlatoria pergandii* Comstock, in Texas; and snow scale, *Unaspis citri* (Comstock) in Florida and Louisiana.

Secondary Pests

Unarmored scale (Coccidae), aphids (Aphididae), mealybugs (Pseudococcidae), and whiteflies (Aleyrodidae) are secondary pests affecting citrus. These insects can assume major pest status in some localities and during certain seasons (Dean et al., 1983). Populations of these pests are usually regulated in most citrus areas by natural enemies and selective chemical sprays such as chlorpyrifos. Pest outbreaks occur when beneficial insect populations are disrupted, e.g., by climatic factors or applications of broad-spectrum, nonselective chemicals. These secondary pests are primarily sucking insects that produce large quantities of honeydew, which in turn favors growth of *Capnodium citri* Berk, or sooty mold fungus. Damage caused by these insects, along with the resultant sooty mold growing on the leaves and fruit, causes serious economic loss by reducing fruit yield and quality. In Texas, uncontrolled infestations of citrus mealybug, *Planococcus citri* (Risso), on producing grapefruit trees causes estimated yield reductions of 3 to 5 percent and fruit grade reduction of 5 to l0 percent (J.V. French, Texas A&I University, unpublished data).

Injurious hemipteran species common to most of the citrus areas are brown soft scale, *Coccus hesperidum* Linnaeus; black scale, *Saissetia oleae* (Oliver); citrus mealybug; citrus whitefly, *Dialeurodes citri* (Ashmead); and green citrus aphid, *Aphis citricola* Van der Goot. Lepidopterous pests include orangeworms, the name commonly used for all moths and butterflies that are pests on California citrus (Klein, 1984). These insects can cause damage by feeding on blossoms, fruit, and foliage. Orangedog, *Papilio cresphontes* Cramer, causes serious defoliation on young trees in Florida and Texas during some seasons.

Ants cause direct or indirect economic loss in all citrus areas. By tending honeydew-producing insects, ants drive off beneficial insects, thereby increasing damage from secondary pests. Leafcutting ants that destroy leaves and green twigs sometimes defoliate and kill young trees (French and Villarreal, 1988). Fire ants feeding on young trees can be severe enough to girdle and kill the trees (Knapp, 1988). Through these feeding wounds on the trees, the fire ants can introduce *Phytophthora* (foot rot) fungus, which weakens and can kill the tree. Fire ants are considered the most serious ant pests in all citrus-growing areas. Fire ants are very aggressive. Their painful attacks on orchard workers have been serious enough that pickers have refused to harvest trees located in areas of heavy fire ant infestations.

The most important ant species that attack citrus are the red imported fire ant, *Solenopsis invicta* Buren, in Florida and Louisiana; red harvester ant, *Pogonomyrmex barbatus* (F. Smith) in Arizona; Argentine ant, *Iridomyrmex humilis* (Mayr) and southern fire ant, *Solenopsis xyloni*, McCook, in California; and tropical fire ant, *Solenopsis geminata* (Fabricius) and Texas leafcutting ant, *Atta texanna* (Buckley) in Texas.

PEST MANAGEMENT

Current Chemical Usage

Survey data show chlorpyrifos 4E is applied to an estimated 264,240 acres (31 percent) of the total 857,000 acres of bearing citrus in the United States. Chlorpyrifos 4E was also used on an estimated 71,475 acres (35 percent) of the combined total of 201,900 acres of nonbearing citrus in Florida and Texas. These States have extensive acreage of young trees planted due to major freezes in 1983 and 1989. Reported chlorpyrifos 4E use on nonbearing citrus was principally for ant control, except that Florida reported some use for orangedog. Additionally, chlorpyrifos 15G was used on an estimated 8,900 acres of bearing citrus (all States) and 12,250 acres of nonbearing citrus in Texas and Florida. All States reported that chlorpyrifos 15G use was for orchard ant control.

Chlorpyrifos usage varies from year to year in all citrus production States, depending mostly on fluctuations in citrus acreage (for example, from major freezes) and to a lesser extent, on seasonal changes in pest infestation levels.

In Arizona and California, oranges, lemons, and grapefruit are grown principally for the fresh market. Insects such as scales and mealybugs, which cause cosmetic fruit blemishes that affect marketability, are controlled by timely spray applications of chlorpyrifos or alternative insecticides.

In Arizona, chlorpyrifos 4E is the most effective chemical for controlling sporadic outbreaks of citrus mealybug, soft scales, and California red scale. Red scale has become a more prevalent and serious pest on both Yuma Valley and Yuma Mesa citrus, where control has increasingly relied on chlorpyrifos (J.C. Palumbo, University of Arizona, 1991, personal communication). Both chlorpyrifos 4E and 15G are applied to nests of red harvester ant.

In California, chlorpyrifos 4E is used primarily for controlling California red scale and secondarily for unarmored scale, mealybug, katydid (Tettigoniidae), and orangeworm outbreaks. The timing of chlorpyrifos sprays for red scale is related to male flight phenology as monitored by pheromone traps (Walker, et al., 1991, 1990a, 1990b). Use of chlorpyrifos and alternative chemicals for red scale control is greater in the San Joaquin Valley than in the interior and coastal citrus regions of California. In the San Joaquin growing regions, the wasp parasitoid, *Amitus melanius* DeBach, normally controls California red scale biologically, unless it is disrupted by ants or nonselective chemical treatments (Klein, 1984).

In California orchards, sprays and granules of either chlorpyrifos or diazinon are used for ant control. These chemicals are used in two manners: by treating nests directly, and by establishing insecticide barriers around tree trunk bases to prevent the Argentine ant and southern fire ant from invading trees and tending the honeydew-secreting insects (Moreno et al., 1987).

Texas grapefruit and oranges are grown principally for the fresh market. Chlorpyrifos is used for controlling California red and chaff scale, the major scale pests of Texas citrus. Citrus orchards are monitored in the early season for scale crawler emergence, with chlorpyrifos sprays timed (usually May-June) to prevent crawlers from settling and developing on fruit, leaves, and wood. Chlorpyrifos sprays are also applied on an "as needed" basis in newly planted orchards to prevent scales from damaging and killing young trees.

Chlorpyrifos sprays and granules are applied as direct ant nest treatments to control tropical fire ant and Texas leafcutting ant on the orchard floor. Chlorpyrifos is also used as a trunk treatment on young trees to prevent cambium and girdling injury by tropical fire ant. A chlorpyrifos and fungicide mixture is sprayed or painted on the trunks prior to applying freeze-protectant tree wraps in the fall.

More than 90 percent of Florida's citrus production is for the processing market; thus, cosmetic fruit injury is of less concern. Areas such as Indian River, where fresh market grapefruit is grown, are an exception. In these areas, a more rigorous and well-timed program of chlorpyrifos and alternative chemical sprays is used to control periodic outbreaks of citrus mealybug, black scale, citrus whitefly, and snow scale.

For control of imported fire ants on nonbearing citrus, where young tree losses from ants may exceed $900 per acre, chlorpyrifos is applied as trunk treatments under freeze-protectant wraps, as orchard floor treatments by boom sprayer, or by chemigation (Banks, et al., 1991). Chlorpyrifos is frequently used in tank mixes with herbicides applied to the orchard floor of bearing citrus (Singh, et al., 1986). Chlorpyrifos granules are applied directly to ant nests or broadcast on the orchard floor by a fertilizer spreader.

A small citrus industry of limited acreage is located in southern Louisiana (Plaquemines Parish) where specialty fresh market Satsuma mandarins and Temple oranges are grown. The hemipteran pest complex is similar to pests affecting citrus in Florida, where chlorpyrifos is used mainly to control Florida red scale, *Chrysomphalus aonidum* (Linnaeus); Florida wax scale, *Ceroplastes floridensis* Comstock; citrus mealybug; citrus rust mite; and citrus red mite.

Chemical Alternatives to Chlorpyrifos

Registered chemical alternatives to chlorpyrifos for control of hemipteran citrus pests are azinphos-methyl, carbaryl, diazinon, dimethoate, ethion, methidathion, malathion, methomyl, and petroleum spray oil.

Phosmet (50W) is currently registered for control of California red scale and brown soft scale (California, Arizona, and Texas only). While current use is limited, phosmet's demonstrated efficacy against red scale (French, 1978), citrus mealybug (French, 1979), and bayberry whitefly on lemons (Walker et al., l984) makes it a viable alternative chemical for inclusion in the pest management programs in States where it is registered.

Registered chemical alternatives to chlorpyrifos for ant control are bendiocarb and fenoxycarb on nonbearing citrus. Since chlorpyrifos is the only registered chemical for controlling pests on bearing citrus crops, obtaining a bearing citrus registration for fenoxycarb and/or bendiocarb will be imperative if the registration for chlorpyrifos is canceled.

Comparative Performance

Chlorpyrifos is preferred over alternative insecticides because it controls a wide range of citrus pests, is nonphytotoxic, and generally does not upset biological control programs. Azinphos-methyl, methidathion, methomyl, and parathion are all Restricted Use pesticides, which limits their use in most citrus-growing areas.

In efficacy tests conducted in Arizona and California against California red scale, chlorpyrifos, methidathion, parathion, and carbaryl gave equivalent control. All of these chemicals were superior to Narrow Range 415 oil. However, all scalicides, except chlorpyrifos and NR 415 oil, increased populations of citrus red mite, *Panonychus citri* (McGregor), with the effect lasting for 11 months after treatments of methidathion and carbaryl in California (Walker and Aitken, 1990; anonymous, 1989). This effect has been attributed to the particularly toxic and long-lasting effect the alternatives have on the wasp parasitoid that is a parasite of the California red scale.

For Argentine ant and southern fire ant, both chlorpyrifos sprays and granules provide quicker knockdown and longer-lasting control than diazinon granules (G.E. Carman, University of California, 1991, personal communication).

In Arizona, chlorpyrifos has shown greater efficacy against citrus mealybug and California red scale than azinphos-methyl and carbaryl. Malathion treatments are as effective as chlorpyrifos for controlling mealybug, except that more treatments are needed when using malathion (J.C. Palumbo, University of Arizona, 1991, personal communication).

In Texas, chlorpyrifos, methidathion, and petroleum oil spray treatments were all equivalent or superior to azinphos-methyl for controlling the chaff scale and California red scale (French, 1975). All treatments controlled immature stages of citrus mealybug, but were less effective against adult stages (French and Reed, 1979). However, a study demonstrated that the residual toxicity of azinphos-methyl, methidathion, and ethion resulted in a high mortality of *Pauridia pergrina* Timberlake, the dominant parasite of citrus mealybug in Texas citrus.

Up to 1 percent of the under-2-year-old nonbearing citrus trees may be damaged or killed by tropical fire ant and Texas leafcutting ant. Both ant species are more effectively controlled by chlorpyrifos than by bendiocarb treatments (J.V. French, Texas A&I University, unpublished data).

In Florida and Louisiana, chlorpyrifos provides citrus growers with effective and inexpensive control against citrus mealybug, soft scales, citrus whitefly, and snow scale (C.C. Childers, University of Florida, 1991, personal communication). While azinphos-methyl and methidathion also control this hemipteran pest complex, citrus red mite and Texas citrus mite populations build up after use of these chemicals (Knapp, 1983). Petroleum oil does not control snow scale or citrus mealybug, and malathion and dimethoate are ineffective against snow and black scale (Knapp, 1991). Phytotoxic effects such as leaf drop and fruit burn can occur following petroleum oil or petroleum oil plus ethion sprays when applied during periods of low humidity.

For red imported fire ant control in nonbearing citrus, fenoxycarb is used more often than chlorpyrifos or bendiocarb. Fenoxycarb's effectiveness is longer term, as opposed to the multiseasonal applications needed for chlorpyrifos or bendiocarb to achieve similar levels of fire ant control (Knapp, 1991). However, within established groves, as much as 3 percent of the trees are replaced each season. This results in having up to 9 percent of the total bearing acreage actually containing nonbearing trees. Therefore, the use of a product like fenoxycarb, which is registered for nonbearing trees only, is illegal under these circumstances (J.L. Knapp, University of Florida, 1991, personal communication).

In Louisiana, chlorpyrifos is used in preference to alternative insecticides because it provides broad-spectrum control of scale insects, mealybugs, and whitefly. Chlorpyrifos also suppresses citrus rust mite, *Phyllocoptruta oleivora* (Ashmead). More applications of dimethoate, malathion, or diazinon are needed to attain similar levels of target pest control (D.K. Pollet, Louisiana State University, 1991, personal communication).

Nonchemical Alternatives

Biological control is the most important nonchemical alternative for managing on-tree citrus pests. Beneficial insect species include both predators and parasitoids, with the latter generally more important on citrus. Because citrus is perennial, once beneficial species become established, they provide long-term regulation of the target pest population, unless disrupted by nonselective chemical sprays, unfavorable orchard management practices, or climatic extremes. While biological controls have been successful in citrus, the development and implementation of these controls require a major commitment of time, research effort, and money. Currently, there are no effective biological controls for ants in citrus.

Pesticide Resistance

Programs are being implemented in most U.S. citrus production areas for early detection of resistance development to organophosphate and carbamate insecticides by hemipteran pest species. Three strains of California red scale showed no evidence of resistance to chlorpyrifos or other organophosphate and carbamate insecticides in recent California tests (Walker, et al., 1991).

In the Union of South Africa, California red scale developed cross resistance to organophosphate insecticides in the mid-1970's, forcing that citrus industry to rely on petroleum spray oils for control of red scale (Georgala, 1975).

Impact on Beneficial Insects

Except for a few tangerine varieties and navel oranges under some conditions, insect pollination is not of major concern in citrus. Pesticide applications seldom coincide with anthesis (i.e., when the plants are in bloom), which is the time when insect pollination peaks.

FUTURE PEST MANAGEMENT OPTIONS

Because chlorpyrifos has been in significant commercial use for less than 10 years, field studies and related information from either the scientific or user community are limited. In addition, when a newly introduced chemical proves highly effective, the use of alternative controls tends to decrease, as do relevant data comparing the respective efficacies of new and old materials.

The cancellation of the chlorpyrifos registration would significantly impact all citrus-producing States and regions by: (1) forcing reliance on alternatives and other organophosphates, carbamates, or oils that are more detrimental to beneficial insects and tree/fruit physiology, thereby disrupting Integrated Pest Management Programs, (2) requiring more frequent or more concentrated sprays, along with increased worker exposure, which will increase environmental and operational risks as well as costs, (3) leaving growers with no effective means of ant control in citrus-bearing orchards.

SUMMARY

Chlorpyrifos is one of the most important and widely used insecticides for citrus crops in the United States. It provides effective control of economically important citrus pests such as scale insects, mealybugs, whiteflies, aphids, and certain lepidopteran species. Chlorpyrifos is also used extensively to control ants in both bearing and nonbearing citrus orchards. Cancellation of chlorpyrifos registration will cause a notable economic impact in the U.S. citrus industry.

Chlorpyrifos Use on Cranberry

Susan E. Rice Mahr

INTRODUCTION

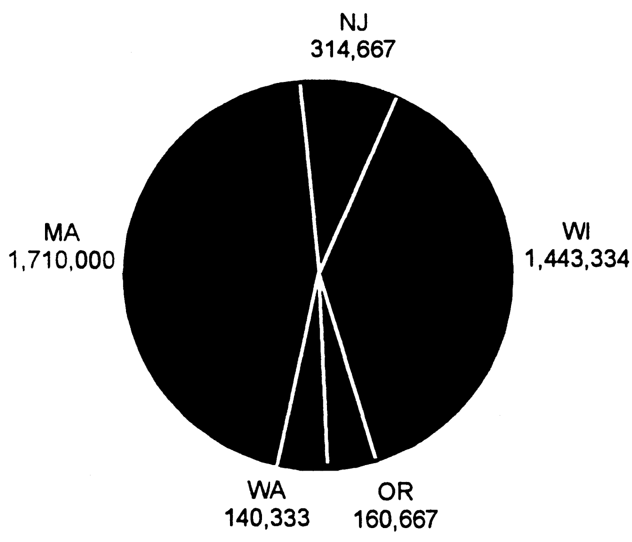
Cranberry, *Vaccinium macrocarpon* Ait. (Ericaceae), is a native, perennial, semi-evergreen, woody vine grown commercially in moist, well-drained, acidic peat bog or sandy soil beds that are surrounded by ditches and dikes. Surface waters, such as lakes, streams, and ponds are used for a constant water supply necessary for many crop management practices. Fruit production on more than 27,000 acres in Massachusetts, New Jersey, Wisconsin, Oregon, and Washington between 1987 and 1989 averaged more than 373 million lb per year, with a value of more than $165 million (Figure 19).

Chlorpyrifos 4E is registered to control the blackheaded fireworm, the yellowheaded fireworm, the cranberry fruitworm, the brown spanworm, the sparganothis fruitworm, cutworms, and the cranberry weevil. Insecticide should be applied at 1.5 lb a.i. per acre by either ground, aerial application, or chemigation, with a maximum of two applications per year and a 60-day interval before harvest.

PEST INFESTATION AND DAMAGE

Cranberry fruitworms occur in all cranberry-producing areas (Dana and Klingbeil, 1966; Marucci, 1977; Shawa et al., 1984); however, this pest is most damaging in Wisconsin and Massachusetts (Brodel and Roberts, 1984a). The cranberry fruitworm, *Acrobasis vaccinnii* Riley, is the most economically important insect pest of cranberry, causing direct damage to berries (Lasota, 1990). Larvae feed only on developing berries, consuming seeds and pulp before moving to an adjacent fruit (Franklin, 1948; Maxwell and Morgan, 1951). Three to six berries are normally eaten by each larva (Franklin, 1948).

Figure 19. Cranberry Production, 1987-89 Average [Total = 3,769,000 100-pound barrels]



Source: Noncitrus Fruits and Nuts 1989 Summary, NASS, USDA.

The blackheaded fireworm, *Rhopobota naevana* (Hubner) is an important pest in all cranberry-growing States (Dana and Klingbeil, 1966; Marucci, 1977; Shawa et al., 1984; Roberts and Brodel, 1985), but may be distributed unevenly in bogs (Shanks et al., 1990). This pest overwinters in the egg stage on cranberry leaves. The larvae hatch in early spring, feeding primarily on terminal foliage and frequently destroy the buds. The blackheaded fireworm larvae then pupate on the bog floor. Second-generation larvae hatch in midsummer and feed on foliage, flowers, and fruit (Dittl, 1988). Yellowheaded fireworm, *Acleris minuta* (Robinson), is an occasional pest in East Coast bogs. This insect is rarely (if ever) found in Wisconsin or the Pacific Northwest.

The brown spanworm, *Ematurga amitaria* (Guenee), is a sporadic pest in Wisconsin and East Coast areas, causing serious losses when populations are high. This insect is not found west of the Rocky Mountains. Larvae feed on foliage, buds, blossoms, and occasionally immature fruit by excavating the surface layer (Franklin, 1948). Several other species of spanworm attack cranberry, causing similar damage.

The sparganothis fruitworm, *sparganothis sulfureana* (Clemens), is a primary pest on the East Coast (Marucci, 1977), is a minor pest in Wisconsin (Hardenberg, 1908), and does not occur in the Pacific Northwest (Chapman and Lienk, 1971). The larvae of the first generation feed on new foliage and flowers, often webbing one or more terminals together. Second-generation larvae not only feed on foliage, but also bore into the fruit and consume three to five berries during development (Beckwith, 1938).

Several species of cutworms, including the black cutworm, *Agrotis ipsilon* (Hufnagel), and *Agrotis niger* (Linneaus), infest cranberry only occasionally. However, these insects cause significant damage by feeding on new growth or girdling young plants (Shawa et al., 1984).

Cranberry weevil, *Anthonomus musculus* Say, is a primary pest on the East Coast (Brodel and Roberts, 1984b); causes damage occasionally in Wisconsin (Dittl, 1988); and does not occur west of the Rocky Mountains (Lacroix, 1926). This pest overwinters in the adult stage, which becomes active in the spring and feeds on new leaves, unopened blossoms, and terminal buds as the plants develop. Females oviposit in holes drilled into unopened blossoms, and larvae feed on developing buds and blossoms. After adult emergence, beetles attack immature fruit (Franklin, 1948), causing noticeable indentations on the fruit surface, which reduces fruit quality (Lasota, 1990).

PEST MANAGEMENT

Current Chemical Usage

Chlorpyrifos is used in all cranberry-producing States on 21 to 48 percent of the cranberry acreage to control blackheaded fireworm and cranberry fruitworm in all States, and *Sparganothis* fruitworm, cranberry weevil, and spanworms in Wisconsin and East Coast areas (Figure 20). Chlorpyrifos use is highest in Massachusetts and New Jersey (48 and 44 percent), where all cranberry pests are prevalent; less in Wisconsin (29 percent), where many of the pests are sporadic; and lowest in Oregon and Washington (21 and 15 percent) where several pests for which chlorpyrifos is registered do not occur. Parathion, which in 1991 lost registration on cranberry, was the dominant insecticide. Adjustment in insecticide usage patterns following the cancellation of parathion is expected to involve increased usage and a greater role for chlorpyrifos in cranberry production pest management.

Chemical Alternatives to Chlorpyrifos

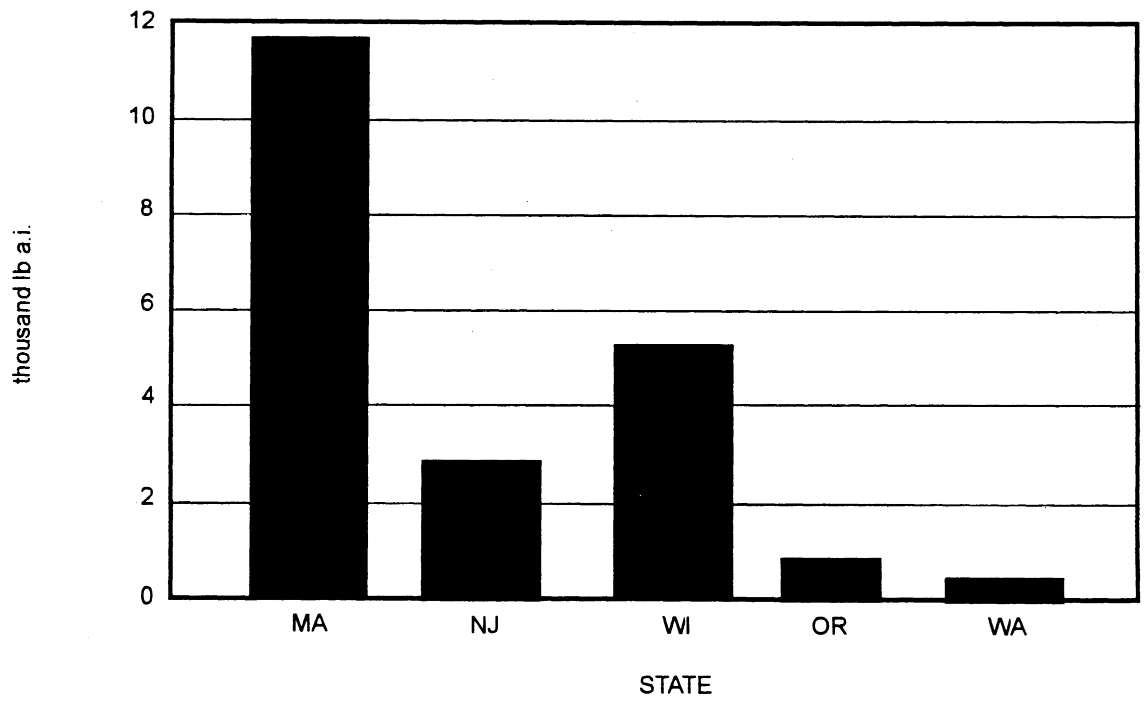
Alternative insecticides for control of these pests are: acephate (for fireworms, *Sparganothis*, spanworms, cutworms); azinphos-methyl (fireworms, fruitworms, cranberry weevil in Massachusetts); carbaryl (fireworms, fruitworms, cutworms); diazinon (fireworms, fruitworms, cutworms); malathion (fireworms); methoxychlor (cranberry fruitworm); and Dipel ES (spanworms).

Alternative chemicals that have been used extensively for control of blackheaded fireworm and cranberry fruitworm are parathion and diazinon. However, diazinon is used minimally in New Jersey because labeling prevents aerial application. With the loss of parathion, the use of diazinon as well as other chemicals will increase. Azinphos-methyl is used extensively in New Jersey, but much less frequently in other States. Acephate, carbaryl, and malathion are generally used less frequently, although they may be of great importance in some States. Methoxychlor is used on less than 1 percent of the national acreage. Dipel was used on 5 percent of the Massachusetts acreage (which constitutes 2.2 percent of U.S. acreage) and on less than 1 percent of the acreage in all other States.

Comparative Performance

Chlorpyrifos is effective at controlling several insect pests on cranberry. It provides excellent control of blackheaded fireworm and cutworms in Oregon, and is a preferred material for blackheaded fireworm, especially in Wisconsin (D.L. Mahr, 1991, personal communication). Chlorpyrifos reduced losses due to cranberry fruitworm in Massachusetts from 40 percent to 2 percent (Brodel, 1986b), and gave slightly better control than other registered insecticides (Brodel, 1984). In some experiments, parathion and diazinon AG500 gave slightly better control of cranberry fruitworm than chlorpyrifos, although all insecticides used reduced cranberry fruitworm fruit infestations (Brodel, 1987). Chlorpyrifos and diazinon were the only

Figure 20. Chlorpyrifos 4E Use on Cranberry, 1987-89 Average
[Total = 21,114 lb a.i.]



insecticides that significantly reduced injury caused by *Sparganothis* fruitworm. Chlorpyrifos provides the best control of the cranberry weevil, for which there are few alternatives (except a Section 24C label for azinphos-methyl in Massachusetts). Chlorpyrifos also controls the cranberry girdler, *Chrysoteuchia topiaria* (Zeller), but is not labeled for this use (C. Shanks, 1991, personal communication).

Acephate is effective for controlling blackheaded fireworm, spanworms, and cutworms. However, acephate is limited to a single application per year, and is used primarily as a prebloom application because of a 90-day preharvest interval. Acephate is suspected of causing a flavor change in processed fruit, and some growers believe it is also a honey bee repellant.

Azinphos-methyl, limited to three applications per season, is effective for controlling fireworms and fruitworms, as well as another major pest, the cranberry tipworm, *Dasineura oxycoccana* (Johnson). The cranberry tipworm is not controlled by chlorpyrifos. However, azinphos-methyl use is not readily accepted by growers, possibly because of its high toxicity (oral LD_{50} of 13).

Diazinon is also effective against many of the pests chlorpyrifos is used to control. Because of diazinon's short preharvest interval (7 days), it may be applied several times per year. Diazinon's toxicity to waterfowl is a principal concern for use in cranberry.

Because of their short preharvest interval, carbaryl and malathion are useful for late-season pest control. Malathion is least effective in cool weather.

Nonchemical Alternatives

Cultural and biological controls are not yet viable options to replace chlorpyrifos use. Spring flooding can control blackheaded fireworm or reduce the need for insecticide use (Smith, 1903, 1984; Cockfield and Mahr, 1992); however, because of difficulties with timing, and the possibility of damage to plants, this is not a widely used management practice (Marucci and Moulter, 1987). Floods in June or July have successfully eliminated fireworms without plant damage if the dissolved oxygen levels in the flood water were high (Nash and Stevens, 1942).

Bacillus thuringiensis var. *kurstaki* is registered as Dipel ES for use in cranberry to control certain lepidopterous caterpillars. Its use and effectiveness as a pest management practice has been limited by its short persistence. Application of *Bacillus thuringiensis* with adjuvants or encapsulating agents may prolong biological activity (Burke and Dapsis, 1991), thus making it a more viable alternative control.

Pesticide Resistance

There has been no documented resistance to chlorpyrifos among cranberry insects, although resistance to some organophosphate insecticides is suspected in certain areas. Growers indicate that blackheaded fireworm and *Sparganothis* fruitworm are not readily controlled by organophosphate insecticides (specifically parathion) (D.L. Mahr, 1991, personal communication). Many cranberry insects feed exclusively on cranberry; therefore, most of these insect populations have few individuals that escape exposure to pesticides. When possible, chemical rotation is recommended to delay development of resistance.

Impact on Beneficial Insects

Honey, bumble, and wild bees are necessary for cranberry pollination (Filmer and Doehlert, 1952; Marucci, 1966; Johansen, 1967). Chlorpyrifos is highly toxic to honey bees and other pollinators. Use of this insecticide during blossom will result in severe bee losses (Lunden et al., 1986). Applications made when 2 percent or more of the flower buds are open may kill a significant number of pollinators. Monitoring pest populations early in the season will help in planning insecticide applications to avoid the bloom period (Mahr et al., 1990).

Integrated Pest Management

The first cranberry IPM program was started by the University of Massachusetts Extension in the early 1980's, and continues to this day (Lasota, 1990). The economic benefit from this program ranged from $73 to $246 savings per acre for 1983-85 (Roberts, 1986). In 1989, the University of Wisconsin completed a 4-year pilot IPM program (Kachadoorian and Mahr, 1990). The Wisconsin IPM program was immediately successful and has been turned over to industry. At this time, 80 percent of the cranberry acreage in Wisconsin is scouted regularly. In Washington, the pilot IPM program started in 1988 by Washington State University has been transferred to the National Grower Cooperative (Bulling, 1991). The National Cranberry Cooperative instituted similar programs in other cranberry-producing States, although Oregon does not have a formal program yet (Bulling, 1991). In Massachusetts and Wisconsin, private consultants offer IPM programs, and in most States some growers implement IPM production technologies themselves (Bulling, 1991).

Pest management procedures developed in IPM programs have improved the timing of pest controls, resulting in a better choice of control methods. The pest populations are detected through regular scouting, and pesticide usage is reduced when pests are not present. Pheromone traps can be used to monitor flight activity of adult blackheaded fireworm and *Sparganothis* fruitworm in order to time insecticide applications (Brodel, 1985; Kachadoorian and Mahr, 1990; Shanks et al., 1990). Economic thresholds have been established for cranberry weevil, cutworms, spanworms, and cranberry fruitworm larvae (Brodel, 1985).

FUTURE PEST MANAGEMENT OPTIONS

Cranberry is a high-value, low-acreage, specialty crop, which makes registration of new products or expansion of current product registrations difficult because of low cost effectiveness to the agrichemical industry. The fact that cranberry is grown in a wetlands environment also contributes to the reluctance of many chemical companies to consider material registrations on cranberry. A label for phosmet is being pursued by the registrant for the control of cranberry fruitworm. Other insects will be added to the label as data are provided. The IR-4 program is supportive of cranberry projects, and is currently engaged in projects involving esfenvalerate, methomyl, and permethrin. It is anticipated that registration of new materials, especially pyrethrins and IGR's, will be difficult in the future because of the potential negative impact of these chemicals on aquatic organisms.

The possibility of biological control of some cranberry pests is currently being investigated. Preliminary studies of field releases of *Trichogramma* wasps indicate some parasitization of blackheaded fireworm eggs (Henderson et al. 1991; Mahr, unpublished data) and cranberry fruitworm eggs (Simser, 1989). An unidentified virus that occurs in Wisconsin may have some value for controlling blackheaded fireworm in the future (Mahr, unpublished data). Research on pheromonal disruption of mating of blackheaded fireworm will be conducted in British Columbia, Canada.

There is a complex of increasingly important cranberry soil insects for which virtually no soil insecticides are registered. Because chlorpyrifos has registered soil use on other crops, in the future the possibility of soil insect use in cranberry might be explored. Many alternative chemicals, such as acephate, azinphos-methyl, and malathion do not have this application.

The *Bacillus thuringiensis* crystal protein gene has recently been successfully genetically engineered into cranberry, offering the potential for plant resistance to lepidopterous pests, although the practical applications of this research will not be realized for a number of years (Serres and McCown, 1990). Entomologists are concerned that this approach may increase the likelihood of resistance developing to *Bacillus thuringiensis*.

SUMMARY

Chlorpyrifos is one of the most efficacious insecticides for the control of several important insect pests of cranberry. This insecticide allows growers to continue to produce high-quality fruit and realize maximum production. With the recent cancellation of parathion's registration, growers will depend more on chlorpyrifos and other chemicals for controlling blackheaded fireworm, cranberry fruitworm, and other insect pests. Chemical alternatives to chlorpyrifos are effective, but dependence on a reduced number of chemicals potentially leads to development of pest resistance. Although cultural and biological controls are being investigated for control of several cranberry pests, the practical implementation of these alternative methods alone for control is not imminent.

The loss of registration on chlorpyrifos for use on cranberry will have a severe impact on the cranberry industry (L. Dapsis, 1991, personal communication). Satisfactory control of some pests could be achieved with alternative chemicals, but chlorpyrifos is critical for control of *Sparganothis* fruitworm and cranberry weevil in Massachusetts and New Jersey, although azinphos-methyl can be used in Massachusetts to control cranberry weevil. In addition, growers will have reduced flexibility in timing and choice of materials and diminished capacity for chemical rotation to prevent development of pest resistance should chlorpyrifos registration be lost. There are currently few insecticides that are effective against the entire pest complex, and one or more alternatives may be lost in the future (as parathion was recently).

Minimal reduction in yield would occur in West Coast States if chlorpyrifos were not available because some alternative chemicals exist that are reasonably effective against blackheaded fireworm and cranberry fruitworm. In Wisconsin and East Coast States, the loss of chlorpyrifos would be detrimental, because pest species are more numerous and pest pressure is more intense in these regions. Growers would need to use more applications of alternative chemicals, that, in many cases, are less effective. In Massachusetts, growers rely almost exclusively on chlorpyrifos to control resistant populations of cranberry weevil and *Sparganothis* fruitworm. The next best alternative is several applications of a full-rate mix of azinphos-methyl, carbaryl, and pyrenone. Without chlorpyrifos, yields will drop and insecticide use will increase, perhaps dramatically (A. Averill, 1991, personal communication).

Chlorpyrifos Use on Fruits and Nuts

Russell F. Mizell, III

INTRODUCTION

This chapter covers a combination of tree and nut fruit crops. The fruit section examines stone fruits (peach, nectarine, plum, prune) as well as pear. The nut section discusses almond, walnut, filbert (hazelnut), and pecan.

These crops form a small, yet high-value market that enhances the need and economic incentive for intensive pest management. Western States are the major production areas for most of these crops, with peaches and pecan having major production areas across the Southern States and into the central Eastern States.

Fruits: Stone Fruits (Peach, Nectarine, Prune, Plum)

USDA's 1990 Agricultural Statistics provided the following information on stone fruits. U.S. peach production averaged 2.4 billion lbs in 1987-89, with California producing more than 60 percent of the national total. The remaining production was widely scattered throughout the United States, with South Carolina, Georgia, New Jersey, Pennsylvania, and Michigan being the next five largest producing States.

California is also the major production State for nectarine. In 1987, California accounted for more than 92 percent of the nectarine production, while Washington, Pennsylvania, and South Carolina together produced another 6 percent (U.S. Department of Commerce, 1987). Nectarine production in California for 1987-89 averaged 441 million lb (USDA, NASS), or about 18 percent of U.S. peach production.

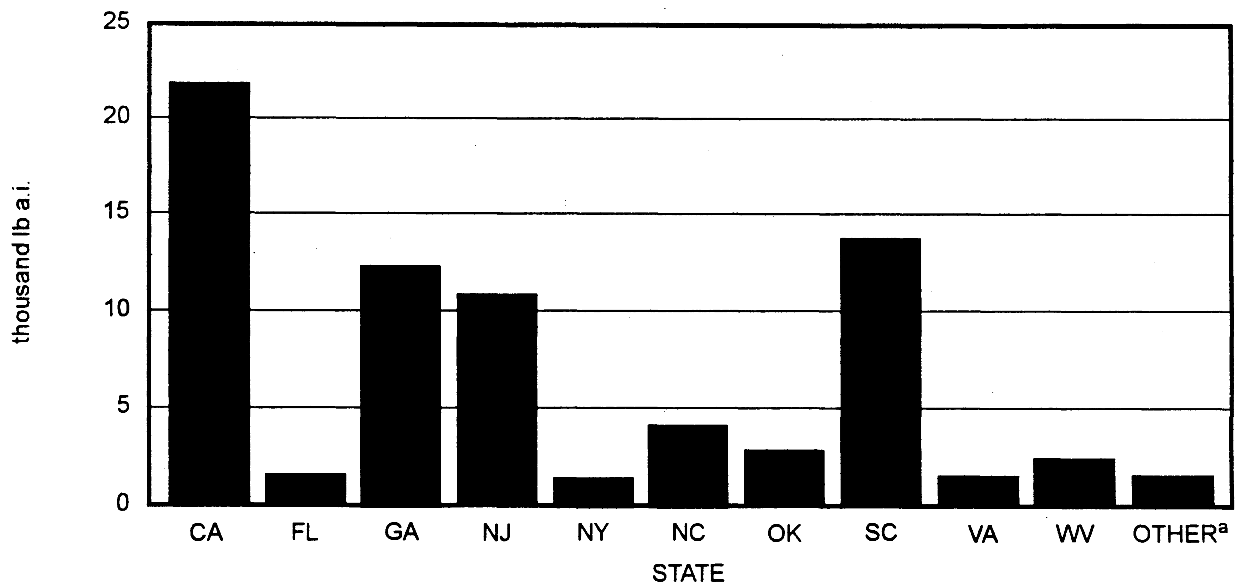
USDA's Non-Citrus Fruits and Nuts 1989 Summary listed plum/prune production at 471,500 tons (1987-89 average). California produced 90 percent of the plums/prunes, with Oregon, Washington, Michigan, and Idaho being the next highest producers.

The average pear production for 1987-89 was 903,000 tons. More than 95 percent of the national production was from Washington, California, and Oregon. New York, Michigan, Pennsylvania, and Connecticut accounted for 3 percent of the remaining production.

Chlorpyrifos 4E is registered to control the peachtree borer, the lesser peachtree borer, European red mite and brown mite, and *Bryobia rubrioculus* (Scheuten). Chlorpyrifos 4E is also registered as a dormant spray for the peach twig borer, the San Jose scale, the mealy plum aphid, and climbing cutworms at the rate of 0.5 to 1.0 pt per 100 gal or 4.0 pt per acre. Figure 21 shows usage of chlorpyrifos 4E on peach.

Chlorpyrifos 4E is registered on pear trees as a dormant or delayed dormant spray at 0.5 to 1.0 pt per acre to control adult

Figure 21. Chlorpyrifos 4E Use on Peach, 1987-89 Average [Total: 72,085 lb a.i.]



[a]Other = AR,OR,WA

San Jose scale; European red mite; brown mite; pear psylla, and climbing cutworms.

Nuts: Almond, Filbert, Pecan, Walnut

California accounts for practically all of the national production of almond and walnut. Almond is the largest commercially produced tree nut crop. The "Agricultural Statistics: 1990" reported that the 1987-89 average almond production in California was 580 million lbs. Walnut production from California averaged 228,000 tons. Oregon produced more than 98 percent of the 17,100 tons of filberts. The other 1 to 2 percent were grown in Washington.

Pecan production occurs throughout the Southern States. The 1987-1989 average production was 175 million lb of pecan in the shell. Georgia, Texas, New Mexico, and Alabama reported 88 percent of the national production.

Chlorpyrifos 4E is registered on almonds as a dormant, or delayed dormant spray for controlling the peach twig borer and the San Jose scale. Recommended rates are 0.5-1 pt per 100 gal or 4 pt per acre of chlorpyrifos, and oil is recommended at a rate of 1-2 percent as a tank mix. One application per season is allowed. In California, the dormant spray is not registered for the counties of Butte, Colusa, Glenn, Solano, Sutter, Tehama, Yolo, and Yuba. Chlorpyrifos 50W and 4E are registered in season for the same pests as a foliar spray at 4 lb per acre, and are restricted to three applications per season.

On filbert, chlorpyrifos 4E at 3-4 pt per acre and 50W at 3-4 lb per acre are registered as in-season foliar sprays for the eye-spotted bud moth, the filbert aphid, the filbert leafroller, the filbertworm, the obliquebanded leafroller, the omnivorous leaftier, and the winter moth.

Chlorpyrifos 4E is registered on pecan at 2 pt/100 gal for use in controlling the black pecan aphid, the hickory shuckworm, and the pecan leaf scorch mite. Chlorpyrifos 4E is also registered for control of the pecan nut casebearer, the fall webworm, *Phylloxera* spp., and the pecan spittlebug (at 1 pt/100 gal). This chemical is also registered for the fire ant and for other ant species as a ground spray at 2 pt per acre. Chlorpyrifos 4E is registered as a tank mix with pyrethroids at 1 pt/100 gal of chlorpyrifos with 2.6 oz of Pydrin 2.4E, or 2.6 oz of Cymbush 3E, or 3 oz of Ammo 2.5E/100 gal against the yellow pecan aphid and the blackmargined aphid. A limit of five applications can be made per season.

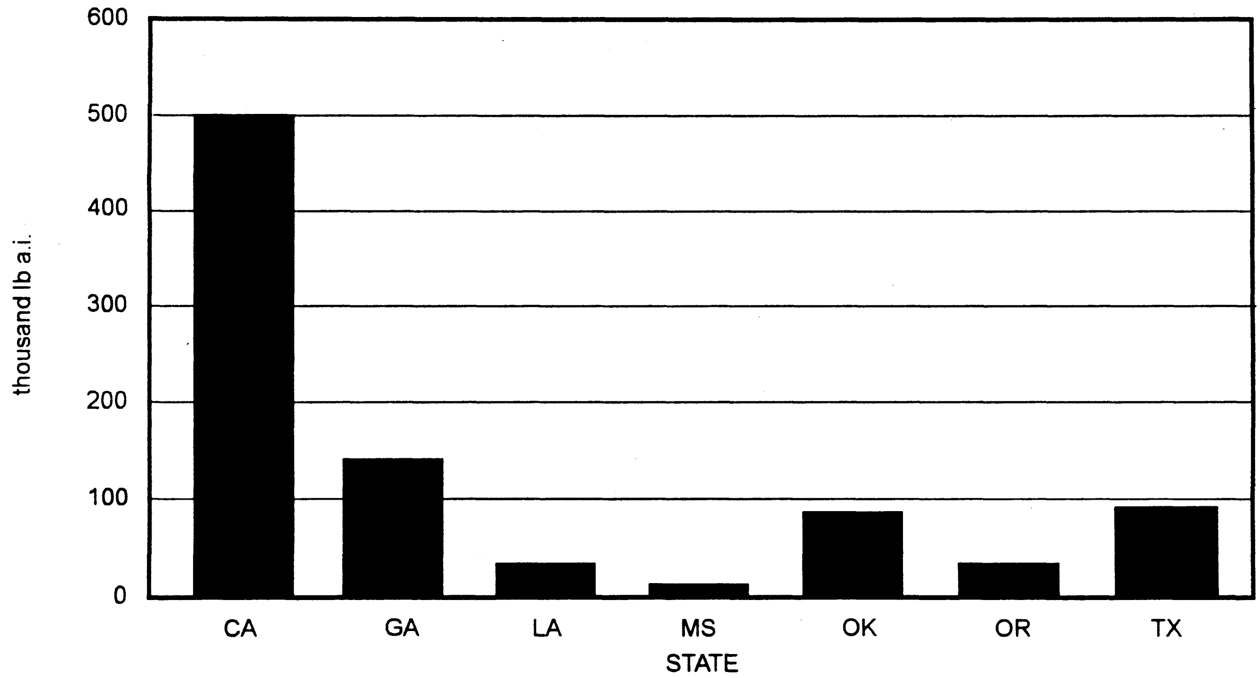
Chlorpyrifos 50W has a registration similar to that of the 4E formulation, but at 1 to 2 lb per acre. Chlorpyrifos 4E is registered on walnut for the codling moth and walnut scale at 4 pt per acre. Only two applications can be made per season. Chlorpyrifos 50W is labeled for dormant and in-season use against walnut scale and codling moth, as well as walnut husk fly, at 4 lb per acre. Only one dormant and two foliar sprays can be applied per season.

Figure 22 shows usage of chlorpyrifos 4E and 50W on nut crops.

PEST INFESTATION AND DAMAGE

Borers—The peachtree borer, *Synanthedon exitosa* (Say), and the lesser peachtree borer, *Synanthedon pictipes* (Grote

Figure 22. Chlorpyrifos 4E and 50WP Use on Nut Crops, 1987-89 Average
[Total lb a.i.: Almond = 81,741; Filbert = 38,850; Pecan = 359,250; Walnut = 420,000]



and Robinson), are primary pests of peach. Lesser peachtree borer occurs throughout the season in the Eastern United States. Populations of the peachtree borer peak in July-August in the Northeast (Mizell and Swift, 1988) and in July-September in the Southeast (Ellis, 1983). The larvae of both species infest the phloem of the trunk and scaffold limbs, and girdle these areas of the tree. Larval entry into the tree is gained through winter-injured bark cracks, disease cankers, and other wounds. If these borers are not controlled, yield will be severely affected, and the trees may die within 2 to 3 years.

The peach twig borer, *Anarsia lineatella* Zeller, an introduced pest from Europe, is a problem in the commercial production of peach, nectarine, plum, and almond in the Western States. The peach twig borer overwinters as a partially grown larva in a protected cell called a hibernaculum. Overwintering larvae become active in early spring about budbreak (Horton and Ellis, 1989). The larvae leave the hibernaculum and burrow into the tender new growth. As many as four generations per year occur in the South. The larvae may feed on several shoots, causing dieback. As fruit with hardened pits becomes available, the larvae enter and damage fruit (Ellis, 1983). The peach twig borer is best controlled when both the insect and the trees are in dormancy. Chemicals applied to control other pests during the fruiting period also suppress the larval infestations.

San Jose scale—The San Jose scale, *Quadraspidiotus perniciosus* (Comstock), is a serious pest of peach, and can cause production loss in nectarine, plum, almond, and pear. This insect overwinters as an immature nymph or adult on the tree and infests foliage, twigs, branches, and fruit. This pest has a very high reproductive potential and can kill limbs in a short period of time. Visible damage or scale on fruit can render fruit unmarketable. Scale are at their lowest populations during the dormant period, when they are easiest to control. San Jose scale is usually a minor pest in the Southeast, but can be of major local importance in California.

The San Jose scale overwinters on pear as nymphs and damages the conductive tissue of the tree. These insects also feed on fruit. San Jose scale occurs in most pear-growing areas, where it attacks a wide range of plant species. Scale feeding causes limb dieback, decreases tree vigor, and may cause tree death. There is a low economic threshold for presence of scales on marketable fruit.

Pear psylla—The pear psylla, *Cacopsylla pyricola* Foerster, the major pest of commercial pear production, overwinters as an adult and moves onto pear from surrounding vegetation (Westigard, 1979). Eggs are laid on new growth, which the nymphs injure through feeding by transmitting a disease-causing pear decline and by producing large amounts of honeydew. Honeydew gives the fruit an off-color and also reduces photosynthesis of the leaves. Control during the end of the dormant period is critical to reduce damage. Oviposition by the adults may begin as early as January and continues into April in Oregon. Thus, several applications of insecticide are necessary for control.

European red mite—The European red mite, *Panonychus ulmi* (Koch), can be a production pest in almond, peach, nectarine, plum, pear, walnut, and apple. The feeding of mites causes foliage to become spotted. As feeding pressure increases, the foliage turns off-color and may even defoliate. Fruit production is also affected, with infested trees producing fewer and smaller fruit. The European red mite passes the winter in the egg stage on the smaller branches and twigs of the host. Hatching occurs in early spring, with nymphs moving to new foliage to feed. Six to eight generations per season are possible. Delayed dormant sprays with a pesticide frequently are the least interceptive management option.

Brown mite—The brown mite, *Bryobia rubrioculus* (Scheuten), is similar in habit to the European red mite. The brown mite closely resembles the clover mite, *Bryobia praetiosa* Koch, and has been confused with it in the past. The brown mite overwinters in the egg stage, and its nymphs hatch slightly earlier than those of the European red mite. Dormant oil sprays with insecticides are the best orchard management options for this mite also.

Navel orangeworm—The navel orangeworm, *Amyelois transitella* (Walker), is the most important pest of almond. This pest is primarily a scavenger, surviving in mummified, discarded, or unpicked fruits. New-crop almonds are also infested, but only after the hulls split. This pest overwinters in the larval stage; however, there is no diapause. Moths begin to emerge in late March and April, but peak in May. As the almond varieties mature, the navel orangeworm attacks the fruit. The almond variety "Nonpareil" is attacked first in July and August. Populations may reach high levels and attack the late-maturing, pollinating cultivars that are harvested in September and October. Cultivar susceptibility is correlated with shell hardness, closing, and availability during the late harvest period (Barnes and Curtis, 1979).

Filbertworm—The filbertworm, *Cydia latiferreana* (Walsingham), is the most serious pest on filbert in the Willamette Valley, Oregon (AliNazee, 1980). Larvae of this native pest overwinter in the ground debris on the orchard floor and in packing houses. Moths begin emergence in late June, with peaks occurring during late July and early August. Eggs are laid on the foliage or near nut clusters. Larval feeding destroys the nut kernel. There is one generation per year.

Filbert aphid—The filbert aphid, *Myzocallis coryli* (Goetze), overwinters on the tree in the egg stage. Aphids emerge in spring. Populations build up rapidly, damaging the trees by removal of plant nutrients. Terminal infestation rates of greater than 15 percent of this pest in early season may affect nut quality, while 20 percent infestation of terminals may be tolerated in July and August. Other pests that sporadically can become production pests of filbert are the filbert leafroller, *Archips rosanus* (Linnaeus); obliquebanded leafroller, *Choristoneura rosaceana* (Harris); and the eyespotted bud moth, *Spilonota ocellana* (Denis and Schiffermuller).

Pests on pecan —Pecans are produced across the Southern United States from California to Georgia. Climatic conditions, as well as cultural and management options, differ dramatically from region to region, as do pest complexes.

Foliar pests include three species of *Phylloxera* that infest pecan in east Texas, Louisiana, Mississippi, Alabama, and southwest Georgia. These insects are early-season foliar pests that must be controlled at budbreak. Pecan phylloxera, *P. devastatrix* Pergande, can destroy an entire nut crop and is an especially important problem (Goff et al., 1989).

The fall webworm, *Hyphantria cunea* (Drury), is found across the pecan belt and is usually a minor, easy-to-control pest that has two generations per year: May to June, and September. Defoliation of individual branches by the larvae may result in fruit abortion. The pecan spittlebug, *Clastoptera achatina* Germar, is an occasional pest in the Southeast. Spittlebugs feed along the stems and terminals on new growth and at the base of nut clusters. Feeding damage at high levels causes abortion or poor quality nuts. Damaging populations are most commonly found in coastal counties of the Southeast (Goff et al., 1989).

The pecan leaf scorch mite, *Eotetranychus hicoriae* (McGregor), is found in the Southeast and is mainly a pest induced through use of pesticides targeted to other pests. However, under hot, dry conditions, scorch mites often reach outbreak levels. Feeding damage by this mite causes the leaves to appear bronzed or scorched and to abort. Abortion of leaves leads to poor quality of the current year's nut crop and poor nut set in the succeeding year.

The yellow pecan aphid, *Monelliopsis pecanis* Bissell, the blackmargined aphid, *Monellia caryella* (Fitch), and the black pecan aphid, *Melanocallis caryaefoliae* (Davis), are major pests throughout the pecan-growing States. Feeding damage by the black pecan aphid causes reduction in photosynthesis and defoliation and may occur at any time during the season. However, black pecan aphid occurs in late season in the Southeast. Yellow pecan aphid populations are bimodal in the Southeast, with an early population peak in May-June and a larger peak in August-September. In Texas and Western States, the yellow aphid populations may occur at any time of the season. These insects are usually found in late season, but are not bimodal. All three aphid species remove photosynthates from the tree and cause defoliation. Early defoliation of pecan results in poor quality of the current year's nuts and poor nut set in the succeeding year. It is well documented that medium-to-high damage from aphids or other defoliators dramatically reduces yield and tree vigor. Leaves with good quality must be maintained on pecan until frost (Dutcher et al., 1984).

The pecan nut casebearer, *Acrobasis nuxvorella* Neunzig, is a serious pest of pecan in New Mexico, Texas, Louisiana, and Mississippi, and is a sporadic pest in Alabama, Georgia, and Florida. This pest overwinters on the tree in a hibernaculum, and emerges at budbreak to feed on shoots. Emerging overwintering moths lay the new brood eggs on the developing nutlets, which the larvae then tunnel into and destroy. Larvae often destroy several nut clusters. The nut casebearer is an early season pest that must be controlled when present.

The hickory shuckworm, *Cydia caryana* (Fitch), is also a nut-feeding pest that occurs wherever pecans are grown. The shuckworm overwinters in nut shucks from the previous year's nuts and in wild hickory nut shucks, which it also infests. The first few generations develop in hickory nuts or on developing pecan nutlets, which abort as a result. Following pecan shell hardening, shuckworms oviposit on the nuts. The larvae then tunnel into, and mine, the shucks. This damage reduces nut quality, causing the shucks to adhere to the shell, which affects shelling after harvest. Four or five generations of this pest occur in the South each year. Only the late summer and fall generations are important on pecan.

The red imported fire ant, *Solenopsis invicta* Buren, is important in pecan orchards because it interferes with harvesting equipment. More importantly, these pests interfere with natural biological control by destroying beneficial insects (Tedders et al., 1990).

Pests on walnut—The codling moth, *Cydia pomonella* (Linnaeus), is the number one pest of early-season, heavy-bearing cultivars of walnuts. There are two generations of this insect, and a partial third generation that occurs each year. The third generation size depends on latitude, coastal influence, and the seasonal climate. On susceptible cultivars, damage may reach 30 to 50 percent or more after the second generation (Riedl et al., 1979). The walnut scale, *Quadraspidiotus juglandsregiae* (Comstock), is a minor walnut pest and seems to be of increasing importance in the central valley of California. Outbreaks occur on a local basis; however, natural factors usually keep walnut scale populations suppressed. The walnut husk fly, *Rhagoletis completa* Cresson, is a native species that invaded California after 1926. This pest has spread throughout the southern part of the State, where it is an annual pest, except in the southern San Joaquin valley, where it is a backyard-tree pest. The fly lays its eggs on the husk, and larvae feed inside the husk. The larvae drop to the ground to pupate and overwinter. This insect has one generation per year, and may diapause for 1 to 4 years. Infestations may reach 100 percent on susceptible cultivars. Larval feeding decreases nut quality (Riedl et al., 1979).

PEST MANAGEMENT

Current Chemical Usage

Nut crops—Using a dormant oil spray and an insecticide is an effective management technique to control borers, scales, aphids, and mites. Dormant oil sprays often fit well into IPM management programs, since these sprays reduce the potential hazard to beneficial insects. Parathion had been widely used in dormant sprays, because it was effective and relatively inexpensive. Chlorpyrifos 4E is registered under California SLN no. 790238 to be added to dormant oil sprays for almond, peach, nectarine, plum, prune, apple, and pear. With the cancellation of parathion usage for fruit and nut crops, it is expected that chlorpyrifos 4E will become even more important as a dormant spray in years to come.

In filbert, 75 percent of the acreage is treated with chlorpyrifos to control aphids and leafrollers. Loss of chlorpyrifos will result in yield losses from aphids, but not from leafrollers.

Pecan pest complexes and their phenologies dictate a variety of chlorpyrifos use patterns. Chlorpyrifos is the only chemical available to control red imported fire ant on pecan orchard floors. In Georgia, 25 percent of the pecan acreage is treated for fire ant control.

Phylloxera spp. are important pecan pests in Louisiana, where 85 percent of the acreage is treated with chlorpyrifos. Chlorpyrifos usage in other States for other pecan pests ranges from 1 to 20 percent. Low yield losses from phylloxera and other pests would occur if chlorpyrifos were unavailable. Chlorpyrifos is used on 60 percent of California walnuts for codling moth.

Fruit crops—Chlorpyrifos use is very important in peach, nectarine, and plum production, because this insecticide is the primary control chemical for the peachtree and lesser peachtree borers throughout the United States. While other pesticides are available, they are not as effective. Minor losses would result if chlorpyrifos were unavailable. Major losses will occur if endosulfan and lindane also become unavailable. Additionally, chlorpyrifos is used on up to 20 percent of the U.S. acreage to control scale, peach twig borer, cutworms, and other minor pests.

In pear, chlorpyrifos use ranges from 1 percent used on the acreage in New York to control pear psylla and up to 75 percent used on Oregon acreage to control scales, mites, and psylla. Low to moderate yield losses in pear would occur if chlorpyrifos were unavailable.

Chemical Alternatives to Chlorpyrifos

Fruits—Chemical alternatives to chlorpyrifos in peach orchards for pest management of peachtree and lesser peachtree borers consist only of endosulfan, esfenvalerate, and cypermethrin. Several alternatives for scale, twig borer, and leafroller control are available, including methidathion, malathion, diazinon, azinphos-methyl, and crop oils. In pear orchards, the chemical alternatives to chlorpyrifos for pest management include amitraz, esfenvalerate, oxythioquinox, permethrin, and cypermethrin for pear psylla; methidathion, diazinon, lime sulfur, and oil for scale; and oil, lime sulphur, methidathion, and diazinon for mites. In plum/prune orchards, the chemical alternatives to chlorpyrifos for pest management consist of diazinon and methidathion for scale, aphids, and twig borer; endosulfan, diazinon, methidathion, oil, phosmet (which is not used) and carbaryl (which is also not used) for cutworms, scale, leafrollers, twig borers, and mites.

Nuts—In almond orchards, chemical alternatives to chlorpyrifos for pest management in season include azinphos-methyl, diazinon, and carbaryl for navel orangeworm, oriental fruit moth, and peach twig borer (with approximately 50 percent of the acreage treated). Diazinon, phosmet, and methidathion are alternatives as dormant applications for peach twig borer and scale (Klonsky et al., 1990). In filbert orchards, the chemical alternatives to chlorpyrifos for pest management of aphids and leafrollers include endosulfan, carbaryl, diazinon, azinphos-methyl, cypermethrin, and permethrin. In pecan orchards, the chemical alternatives to chlorpyrifos consist of azinphos-methyl, esfenvalerate, cypermethrin, diazinon, lindane, oil, carbaryl, dimethoate, endosulfan, malathion, and methomyl. In walnut orchards, the chemical alternatives to chlorpyrifos for pest management include methidathion, azinphos-methyl, and diazinon.

Comparative Performance—Fruit

Peach—Chlorpyrifos is critical to the successful management of borers. Endosulfan and lindane are the only effective alternatives in most States. The increased longevity of chlorpyrifos residues on tree trunks (Yonce, 1980) provides longer residual control from one application. The peachtree and lesser peachtree borers are major pests of peach and other *Prunus* spp. wherever these fruits are grown in the continental United States. Endosulfan is rated as equal to chlorpyrifos, but three other alternatives are rated as inferior: azinphos-methyl (25 percent less effective), cypermethrin (10 percent less effective), and esfenvalerate (10 percent less effective). In Arkansas, oil is rated as 20 percent better than chlorpyrifos (plus oil) for scale control. In California, methidathion is rated equal to chlorpyrifos for control of peach twig borer, whereas diazinon is rated 10 percent better and parathion is rated 20 percent better. For control of the San Jose scale, parathion and diazinon are rated as 10 percent inferior to chlorpyrifos 4E. In Georgia, no alternatives to chlorpyrifos are recommended for control of white peach scale, *Pseudaulacaspis pentagona* (Targioni-Tozzetti). In Oregon, diazinon is rated 20 percent better than chlorpyrifos during dormancy for scale control. In South Carolina, oil is rated as 10 percent inferior to chlorpyrifos for scale control. In Washington, for control of San Jose scale, leafrollers, cutworms, and peach twig borer during dormancy, azinphos-methyl (25 percent), carzol (10 percent), and oil (25 percent) are rated inferior, whereas endosulfan, parathion, methidathion, and diazinon are rated as equal to chlorpyrifos. In Washington (in season), parathion, endosulfan, diazinon, and carbaryl are rated as equal to chlorpyrifos for control of oriental fruit moth, peach twig borer, and San Jose scale. Azinphos-methyl and phosmet are rated 20 percent better than chlorpyrifos. In West Virginia, oil is rated 5 percent inferior to chlorpyrifos for control of San Jose scale during dormancy.

Nectarine—In California, for control of San Jose scale during dormancy, methidathion is rated as equal, and parathion (20 percent) and diazinon (10 percent) are rated as better than chlorpyrifos. For peach twig borer control, methidathion is rated as equal, and parathion and diazinon are rated as 10 percent inferior to chlorpyrifos.

Pear—In New York, during the dormant period for pear psylla, all alternative chemicals—mitac (75 percent), esfenvalerate (40 percent), morestan (50 percent), and cypermethrin (40 percent)—are rated better than chlorpyrifos 4E. In Oregon, for control of scale and mites in the dormant period, methidathion or methidathion plus oil are rated equal to chlorpyrifos; oil (30 percent) or oil plus parathion (15 percent) are rated inferior to chlorpyrifos. Diazinon, lime sulphur, and parathion are rated equal to chlorpyrifos for dormant control of pear psylla, scale, and mites. In Washington, for control of San Jose scale, diazinon and parathion are rated equal to chlorpyrifos, and methidathion plus either parathion or diazinon are rated 25 percent better than chlorpyrifos.

Plum/Prune—In California, for plum in the dormant season, diazinon (10 percent) and parathion (10 percent) are rated inferior to chlorpyrifos, while methidathion is rated as equal for use against scale, aphids, and peach twig borer. For prune, parathion (30 percent) and diazinon (25 percent) are rated inferior to chlorpyrifos against the same three insect species. In Oregon and Washington, for plum during the dormant period, parathion is rated as equal to chlorpyrifos for control of scale, twig borer, aphids, and cutworms. Methidathion (75 percent), azinphos-methyl (75 percent), superior oil (60 percent), endosulfan (20 percent), and diazinon (10 percent) are rated inferior to chlorpyrifos for control of cutworms, scale, peach twig borer, and mites.

Comparative Performance—Nuts

Almond—In California during the dormant season, diazinon, parathion, and methidathion are equivalent to chlorpyrifos. Phosmet provides about 25 percent less control against peach twig borer and San Jose scale. In season, azinphos-methyl is ranked as 20 percent better than chlorpyrifos. Carbaryl (10 percent) and diazinon (15 percent) are less effective than chlorpyrifos for controlling navel orangeworm, peach twig borer, and oriental fruit moth.

Filbert—In Oregon, chlorpyrifos is used on filberts to control the filbert aphid and filbert leafroller. Carbaryl (50 percent) and endosulfan (15 percent) are considered less effective than chlorpyrifos against aphids. Diazinon, azinphos-methyl, and cypermethrin are considered equal to chlorpyrifos. For control of filbert leafroller, endosulfan and azinphos-methyl are considered equal to chlorpyrifos, while carbaryl (30 percent), diazinon (20 percent), and cypermethrin (20 percent) are better than chlorpyrifos.

Pecan—While the pest complex varies across the pecan belt, the chemicals examined are rated relatively the same wherever the same pests occur. Comparatively few chemicals remain available. For control of phylloxera, endosulfan and lindane, the only alternatives, are rated 10 percent better than chlorpyrifos. Chlorpyrifos is the only labeled material for control of fire ants in pecan orchards. Endosulfan is rated 10 percent better then chlorpyrifos for nut casebearer control, whereas azinphos-methyl, malathion, esfenvalerate, methomyl, and cypermethrin are rated as equal to chlorpyrifos.

For hickory shuckworm, azinphos-methyl is rated as equal to chlorpyrifos, while methomyl and carbaryl are rated as 20 percent inferior to chlorpyrifos. Esfenvalerate and cypermethrin are rated 5 percent better; chlorpyrifos, plus a pyrethroid, is rated 10 percent better than chlorpyrifos alone.

For pecan spittlebug control, endosulfan is rated 10 percent and carbaryl 5 percent better than chlorpyrifos respectively; azinphos-methyl is rated as equal; and diazinon is rated as 10 percent less effective than chlorpyrifos.

All of the available alternatives are rated at least 10 percent better than chlorpyrifos for control of pecan aphid. For control of leaf-feeding insects, malathion and dimethoate are rated equal to chlorpyrifos, and esfenvalerate and fenvalerate are rated 5 percent better. Lindane is inferior to chlorpyrifos by 10 percent.

Walnut—In California walnuts, methidathion (50 percent) and azinphos-methyl (75 percent) provide much better efficacy than chlorpyrifos 4E against codling moth. In season, methidathion (50 percent) and azinphos-methyl (75 percent) provide better efficacy against codling moth than chlorpyrifos 50W. During dormancy, methidathion, diazinon, and parathion provide 20 percent better control of walnut scale than does chlorpyrifos.

Nonchemical Alternatives

Fruits—Nonchemical alternatives for peach/nectarine are limited at present. Use of the mating-disruption technique with pheromones appears promising based on preliminary field testing, but has not been recommended to growers (McLaughlin et al., 1976; Snow et al. 1985; Pfeiffer et al., 1991).

Scale pest management alternatives are limited. Under present management practices and economic thresholds, biological controls are not efficacious. Due to the biology of the pest, changes in cultural and management practices to suppress scale do not appear promising. Care is taken to reduce insecticidal hazards to beneficial insects (which have a positive impact in suppressing scale populations).

Nonchemical management alternatives for pear pests include selection of resistant rootstocks and scions, since pear psylla only develops on pear. Plant growth regulators that reduce the availability of new growth where pear psylla nymphs feed appear promising. For the San Jose scale, alternatives are minimal. Natural control from endemic parasites and predators are not sufficient to reduce scale populations below the economic threshold.

Plum/prune host plant resistance and cultural and biological controls are all being investigated as potential management options for pests of plum/prune. However, these alternatives, which need considerably more research, will not take the place of chemicals in the near future.

Nuts—Nonchemical alternatives for almond consist of the sanitation of mummified, discarded, or unpicked nuts; early harvest; and use of cross-compatible varieties for navel orangeworm. Biological controls are being explored, but are not effective at present for either the navel orangeworm or peach twig borer. Alternative pest management options for scales are not available.

Nonchemical alternatives in filbert consist of the use of predators to control filbert aphid (Messing and AliNazee, 1986). Sanitation in the orchard and in packing and storage sheds is important to suppress filbertworm. Natural enemies reduce the filbert leafroller populations in June by as much as 70 percent; therefore, the protection of these natural enemies is essential for leafroller management.

Nonchemical alternatives for the major pecan pests are few. Cover crops of clover and vetch on the orchard floor augment natural predator populations for aphids. Sanitation of shucks in the orchard by disking the orchard floor can suppress shuckworm populations.

Nonchemical alternatives are not available for management of codling moth in walnut plantings. Natural enemies will not suppress codling moth populations below economic thresholds, although research on use of habitat manipulations to enhance beneficial populations is ongoing. Pheromone disruption and trapping are being implemented with limited success. Natural enemies usually control populations of walnut scale. Alternative controls for walnut husk fly are being researched and include management of the orchard floor where the fly pupates.

Pesticide Resistance

Fruit—The potential for the development of resistance by the peachtree borer in peach/nectarine orchards is low because only one application of chlorpyrifos is applied per season. A higher potential exists for peach twig borer and San Jose scale because these insects have several generations per year and are often subjected to all of the chemical applications, regardless of the target pest. Potential for the development of pesticide resistance in pear psylla is documented. Scale also has great potential for development of resistance. However, reduced application of pesticides should allow management of most pests (Westigard, 1979). In plum/prune, the potential for the development of pesticide resistance in the San Jose scale is high; however, resistance management strategies can minimize risk.

Nuts—The potential for the development of resistance to pesticides by scales, navel orangeworm, and peach twig borer in almond is high. In filbert, AliNazee (1983a) documented filbert aphid resistance to carbaryl. Resistance to pyrethroid pesticides by aphids has been documented in pecan by Dutcher and Htay (1985). Pesticide resistance development is probably low for walnut because of the reduced use of broad-spectrum pesticides and the dependence on natural controls for pests such as aphids.

Impact on Beneficial Insects

The protection of pollinating insects (especially honey bee) in all of these orchard crops is essential. The impact on pollinating insects by dormant or borer sprays is minimal, because these applications occur well before or after bloom. When applications of insecticides are necessary near or during bloom, the impact on pollinating insects can be severe if these applications are not properly timed to early morning or late evening. In pecans, honey bee and other pollinating insects forage pecan orchards for aphid-produced honeydew. The populations of these insects can be severely impacted by broad-spectrum sprays from August to October, if the insects are present in the orchards.

Integrated Pest Management—Fruit

Peach/Nectarine—Integrated pest management for borers is limited. Good management practices that maintain healthy, vigorous trees will reduce the impact of borers; however, all trees from second leaf on are at risk to attack and must be protected with chemical sprays. One application of chlorpyrifos between June 15 and September 15 provides good control of both species (Yonce, 1980). Monitoring with pheromone traps can help in timing in-season sprays for peach twig borer and scale. The broad host range of scale and its dispersal ability prohibits the development of IPM tactics for suppression of this pest. However, use of pheromone monitoring may allow better timing of chemicals and reduce pesticide load.

Pear—IPM is limited to the use of cultural and management practices to reduce risk of pear psylla and the San Jose scale. Control of scale with foliar sprays in season has low efficacy, but dormant sprays are usually effective. Pheromone traps for San Jose scale can be used for better timing of sprays.

Plum/Prune—IPM for plum and prune is being developed. Pheromone traps for San Jose scale and peach twig borer enable use of well-timed sprays.

Integrated Pest Management—Nuts

Almond—IPM for navel orangeworm centers on monitoring with oviposition traps in order to time treatments against the first generation. Other practices, such as removal of mummies from the orchard, suppress overwintering populations. Control decisions are based on the previous year's infestation level, level of mummy nuts in the orchard, and proximity of the orchard to other sources of navel orangeworm, i.e., citrus. Pheromone traps can be used to time sprays against the first brood larvae of peach twig borer and to determine the effectiveness of previous dormant treatments. The dormant period is the best time to control scales and peach twig borer, because spraying at this time provides the best coverage, and is least likely to disrupt beneficials such as predatory mites (Barnes and Curtis, 1979). Economic thresholds for peach twig borer, as well as pheromone data, suggest that spraying for the navel orangeworm in May will often control both pests (Reidl et al., 1981). Pheromone traps can be used to time sprays against San Jose scale.

Filbert—AliNazee (1983b) reported that omission of all pesticides led to high populations of the filbertworm, resulting in 20 percent loss of nuts, while filbert leafroller and filbert aphid declined to low levels. Damage from other pests was not observed. Therefore, reduction in pesticide applications should reduce pest outbreaks and IPM should key on the filbertworm. Filbertworm can be monitored with pheromone traps to time sprays. Egg masses on trunks or infested buds in early season can be used to monitor filbert leafroller. Pheromone traps can be used to monitor obliquebanded leafroller. Dormant sprays give good control of eyespotted bud moth.

Pecan—IPM advances consist of sampling and monitoring techniques for aphids; pheromone traps for hickory shuckworm; a phenological model to predict nut casebearer emergence in Texas and winter cover crops; and use of *Bacillus thuringiensis* to control fall webworm and other lepidopteran pests. Aphid management has sought to avoid the use of pyrethroids, except in combination with chlorpyrifos in late season to manage against development of resistance. Control of imported fire ant is becoming increasingly important due to the impact of this insect on biological control agents. Many growers now purchase and release common green lacewing for aphid and mite suppression. Chlorpyrifos is highly toxic to beneficials (Mizell and Schiffhauer, 1990).

Walnut—IPM tools such as pheromone traps and day-degree models are available to better time sprays in order to suppress the codling moth (Rice et al., 1982). Selective use of chemicals that are easy on beneficials causes less disruption to these insects and reduces induction of secondary pests.

FUTURE PEST MANAGEMENT OPTIONS

The outlook for new chemicals in orchard pest management is bleak. Nonchemical controls, such as pheromone disruption of mating, appear to be promising. In pear, the possibilities for the development of resistant rootstocks and scions against scale and psylla seem to offer future management potential. Nonchemical pest management options based on cultural and management practices, such as resistant or pseudo-resistant cultivars (i.e., cultivars with different phenology, earlier or later than pest), pheromone disruption, and orchard sanitation are under development.

Natural enemy conservation and biological controls will become more important management options as the reduction of chemical alternatives continues. New biological information will allow better timed sprays and a more judicious use of the remaining chemical alternatives.

The pecan weevil, *Curculio caryae* (Horn), a nut pest in the Southeast, requires chemical control with carbaryl most seasons. These carbaryl applications are very destructive to natural enemies. The pecan weevil and its management will require more study.

SUMMARY

Fruit

Loss of chlorpyrifos would result in small yield losses from peachtree and lesser peachtree borers because of lower efficacy of alternative management options.

Scale, twig borer, and other pests can be controlled by alternative chemicals. Loss of chlorpyrifos for pear would result in little change in yield from these pests, while for the plum/ prune crop, loss of chlorpyrifos would result in slight yield loss from these pests.

Nuts

For almond, loss of chlorpyrifos in Oregon would result in moderate yield losses from peach twig borer, San Jose scale, navel orangeworm, and oriental fruit moth. Approximately 25 percent of the filbert acreage is treated with permethrin. Other registered products are not currently in use. Loss of chlorpyrifos would result in yield losses from aphids, but not from leafrollers. For the pecan crop, loss of chlorpyrifos would result in slight yield loss from these pests. Loss of chlorpyrifos would not reduce walnut yield.

Chlorpyrifos Use on Grape

John N. All

INTRODUCTION

Grape production in the United States is conducted within four culture groups. The first culture group consists of native cultivars, fox grape, *Vitis labrusca* L., and summer grape, *V. aestivalis* Micheaux. This first group is grown east of the Rocky Mountains. The second culture group is the Muscadine cultivars of *V. rotundifolia* Micheaux, which are grown in the Southeast. The European wine grape *V. vinifera* L. and hybrids, the third culture group, are produced from crosses with U.S. species and are grown primarily in the Western States (Bournier, 1976). The fourth culture group, *V. vinifera* hybrids, recently have been planted in Eastern and Southeastern States with mixed success (Dutcher et al., 1988). Total bearing acreage of grape in the United States during 1987-1989 averaged 759,037 acres, with a mean yield of 7.69 tons per acre. The average annual value of U.S. grape production during 1987-1989 was approximately $1.6 billion (USDA, 1990a).

Chlorpyrifos is labeled for application to soil around grape plants for controlling the grape root borer and cutworms. Chlorpyrifos can be applied on nonbearing vines for controlling cutworms and other foliage feeders. For usage details, see Figure 23. Other products registered for these pests are carbaryl and malathion.

PEST INFESTATION AND DAMAGE

More than 200 different insect pests feed on grape in the United States. Insect pest management is an important aspect of grape production, since different pest species occur in the Eastern and the Western United States (Bournier, 1976; McGiffen and Neunzig, 1985; Dutcher et al., 1988; Barnes, 1970, Flaherty et al., 1982). The potential for yield reduction from pest damage varies considerably in different regions.

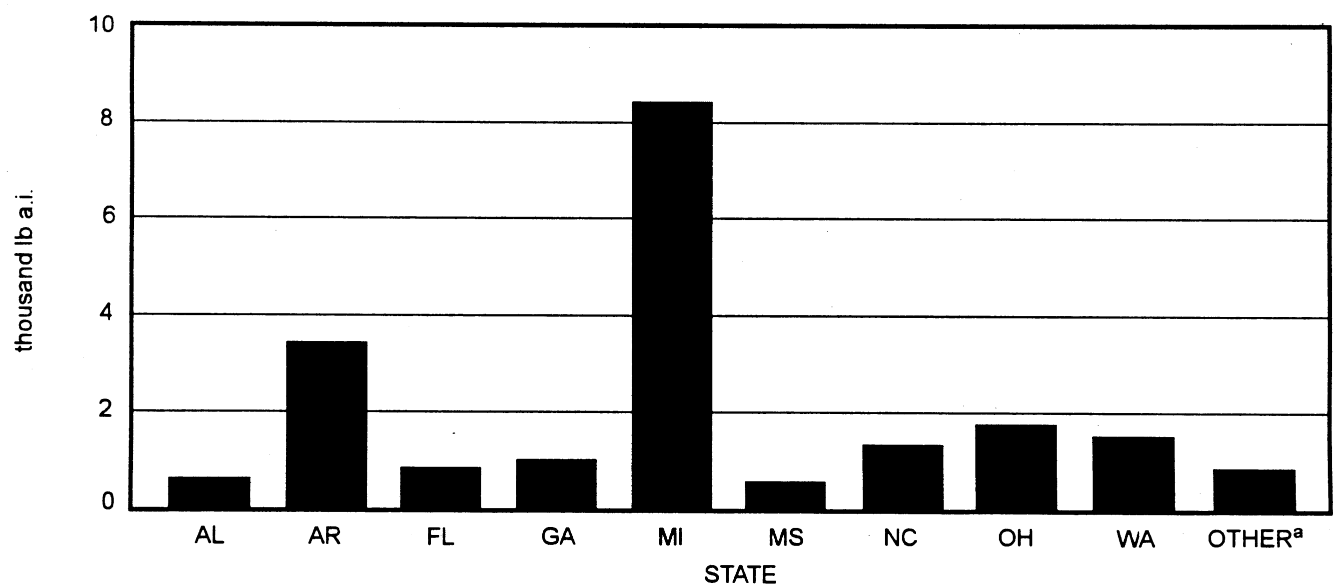
In the Eastern United States, the grape berry moth, *Endopiza viteana* Clemens; the Japanese beetle, *Popillia japonica* Newman; stink bugs, Pentatomidae; leafhoppers and plant hoppers, Homoptera; and bees and wasps, Hymenoptera; feed on grape foliage and fruits. The grape root borer, *Vitacea polistiformis* (Harris), is the most serious pest attacking grape roots in Southeastern United States. In the Western States, the western grape leafhopper, *Erythroneura elegantula* Osborn; the variegated grape leafhopper, *Erythroneura variabilis* Beamer; the omnivorous leafroller, *Platynota sultana* Walshingham; and the western grapeleaf skeletonizer, *Harrisina brillians* Barnes and McDunnough, all have the potential to cause substantial yield loss in grape.

PEST MANAGEMENT

Current Chemical Usage

Chlorpyrifos is used for climbing cutworms in Michigan, Missouri, and to a lesser extent, in Washington. In Texas, chlorpyrifos is sometimes applied as an alternative for malathion, carbaryl, and other insecticides for various foliage feeders, including leafhoppers (*Erythroneura* spp.) and the grape cane girdler, *Ampeloglypter ater* LeConte.

Figure 23. Chlorpyrifos 4E Use on Grape, 1987-89 Average
[Total 19,722 lb a.i.]



[a]Other = MO,SC,TX,VA

Chlorpyrifos is used as a preventive control measure for freshly hatched grape root borer larvae on the soil surface before these pests reach the roots (All et al., 1985). Approximately 36 percent of the 10,000 acres of grape grown in the Southeast are treated for this pest. A limitation regarding the use of chlorpyrifos for the grape root borer is the 35-day preharvest interval for this insecticide when it is applied to grape. The root borer oviposits close to harvest; thus, the preharvest interval limits the ability to use the insecticide during the period when the pest is most vulnerable. All (1989) demonstrated that repeated annual use of chlorpyrifos to vineyard soil will provide effective control of this pest.

Chemical Alternatives to Chlorpyrifos

There are no chemical alternatives to chlorpyrifos for controlling the grape root borer (All et al., 1987a). Carbaryl is sometimes used for controlling climbing cutworms on grape.

Comparative Performance

Although carbaryl can be used for controlling climbing cutworms on grape, this chemical is not as effective as chlorpyrifos. Chemicals such as carbaryl and malathion, which are generally considered safer than chlorpyrifos, are usually chosen first in management of insects that feed on grape foliage in Texas.

Nonchemical Alternatives

The grape root borer can be controlled by mounding of soil under the trellis to prevent pupal emergence. This practice inhibits larvae from reaching the root zone (Wylie, 1972). Use of plastic mulch under the trellis serves a similar function. Both procedures have cultural drawbacks and therefore have not been used extensively by growers. Grape root borer pheromones have been used in mating disruption studies to reduce infestations (Johnson et al., 1986b); however, these chemicals are not commercially available. Weed control and cleanup of fallen fruit and other plant materials in vineyards are generally recommended to prevent pest buildup (Dutcher et al., 1988).

Pesticide Resistance

Insecticide-induced problems, such as resurgence of minor pests, tolerance, or resistance to pesticides have not been reported for chlorpyrifos on grape.

Impact on Beneficial Insects

Biological control is an important aspect of preventive management of insect pests in vineyards, and use of insecticides can be disruptive to this process. Chlorpyrifos residues in soil treated for controlling grape root borer can be lethal to the predator *Harpalus pennsylvanicus* (DeGeer) (Carabidae). However, biological control by carabids is probably not strongly disrupted, because the chlorpyrifos is applied in widely separated strips within a vineyard. Similar numbers of *H. pennsylvanicus* were captured in pitfall traps in chlorpyrifos-treated and untreated grape plots (All, 1989).

Integrated Pest Management

Use of chlorpyrifos for controlling grape root borer is initiated in Georgia when 5 percent of vines have at least one pupal case present at the end of moth flights, and treatments are terminated when counts are reduced to 2 percent or less (Bertrand et al., 1991).

SUMMARY

Chlorpyrifos is used on 2 percent of U.S. grape acreage. Most usage of this chemical is in the Eastern States on nonbearing vines or on soil under vines. Chlorpyrifos is the only insecticide labeled for grape root borer, and is the most effective of all products screened. Elimination of chlorpyrifos would result in substantial yield reduction for grape in the Southeastern United States. Chlorpyrifos use is minimal for climbing cutworms and various foliage feeders; however, this chemical's availability for these pests is regarded as critical by Michigan scientists. Chlorpyrifos use on grape production in the Western United States is minimal.

Chlorpyrifos Use on Strawberry

Susan E. Rice Mahr

INTRODUCTION

Strawberry, *Fragaria xananassa* Duch., is a herbaceous perennial grown for both fresh market and processing uses on 46,300 acres throughout the United States (1987-89 average). California, Florida, Michigan, Oregon, and Washington are the major strawberry producers. There is also a growing "pick-your-own" production of this crop in most States.

Chlorpyrifos 4E is registered for use in strawberry production to control the strawberry bud weevil. For usage details, see Figure 24. The recommended application rate for controlling the strawberry bud weevil is 1 lb a.i. per acre when buds first appear. If needed, chlorpyrifos is again applied 10 to 14 days later. Applications are limited to no more than two treatments per season. Chlorpyrifos is also registered as an SLN in Idaho, Oregon, and Washington for application as a soil pre-plant incorporation in the spring to protect against the garden symphylan the following year.

Carbaryl and methoxychlor are the only alternative chemicals used for strawberry bud weevil control. Alternate chemicals for controlling garden symphylan are endosulfan (which is used as a plant dip in the Northwest) and fonofos.

PEST INFESTATION AND DAMAGE

Strawberry bud weevil, *Anthonomus signatus* Say, is a native, univoltine insect found in most areas east of the Rocky Mountains (Headlee, 1918). Bud weevil is an important pest of strawberry, especially for early-maturing varieties of this crop. This pest feeds on wild and cultivated strawberry and on *Rubus* spp. (Shanks and Sjulin, 1988). The life history of the strawberry bud weevil, and this pest's interaction with cultivated strawberry, are described by Headlee, 1918, and Williams and Rings, 1980.

Yield reductions can be as high as 50 to 100 percent, although infestations of fields may be sporadic and unpredictable (Baerg, 1923; Schaefers, 1978). The strawberry bud weevil most often attacks strawberry fields adjacent to wooded areas, where this pest overwinters. The garden symphylan, *Scutigerella immaculata* (Newport), lives in the soil and feeds on the strawberry's fine roots and root hairs. The symphylan is an occasional pest in new strawberry plantings in the Pacific Northwest.

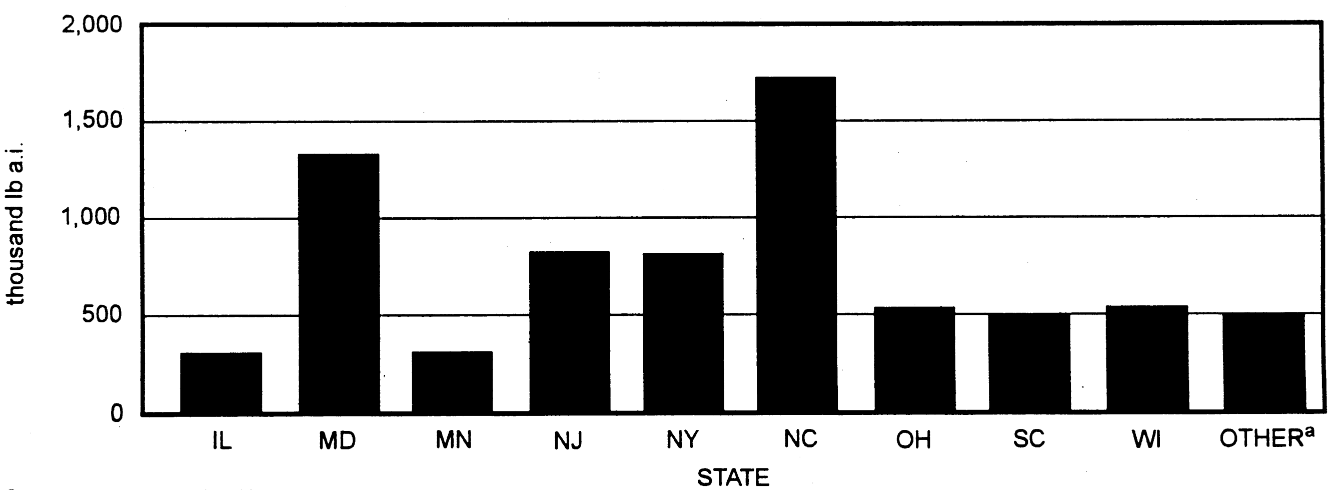
PEST MANAGEMENT

Current Chemical Usage

Chlorpyrifos is used to control strawberry bud weevil on 75 to 100 percent of the strawberry acreage in New Jersey and Maryland. In the Carolinas, Kentucky, and New York, 30 to 40 percent of the acreage is treated with this chemical. In the Midwest, chlorpyrifos is used on 10 to 20 percent of the acreage, and in New England this pesticide is used on less than 5 percent of the acreage. Use of chlorpyrifos to control garden symphylan has not been reported.

Carbaryl is used in only four States, with significant usage in South Carolina. In most States, methoxychlor is used on less than 5 percent of the acreage. In many States, insecticides not registered specifically for strawberry bud weevil control, such as azinphos-methyl, are applied for other pests. (These insecticides, coincidentally, also provide control of strawberry bud weevil.)

Figure 24. Chlorpyrifos 4E Use on Strawberry, 1987-89 Average [Total 7,317 lb a.i.]



[a]States: AR,CN,IN,KY,NH

Comparative Performance

Chlorpyrifos provides satisfactory control of strawberry bud weevil even at rates lower than one lb a.i. per acre (Williams, 1979; Race, 1985). Chlorpyrifos was the most effective chemical used in laboratory tests and the most consistent pesticide used in field trials among the numerous chemicals tested for strawberry bud weevil control (Schaefers and Labanowska, 1978). In field tests, weevil damage was reduced 79 to 93 percent by chlorpyrifos (Schaefers, 1978). Both chlorpyrifos and fonofos provided good control of garden symphylan in strawberry (Fisher and Morris, 1987). Carbaryl is not as effective as chlorpyrifos for strawberry bud weevil control, since carbaryl requires several applications and may aggravate aphid and mite problems. Two applications of methoxychlor do not provide satisfactory control of strawberry bud weevil when populations are high (Race, 1985). This chemical has a shorter residual period than chlorpyrifos, and therefore would probably require multiple applications. Azinphos-methyl and parathion were as effective as chlorpyrifos (Williams, 1979), although recent research has proven these chemicals inferior for strawberry bud weevil control.

Nonchemical Alternatives

Avoidance of sites near wooded areas is a successful although often impractical cultural control method for strawberry bud weevil (Vincent et al., 1990). There are no other effective cultural or biological controls for strawberry bud weevil (van Driesche and Hauschild, 1987).

Pesticide Resistance

The potential for strawberry bud weevil resistance to chlorpyrifos is relatively minimal. Not only does this pest have alternate hosts, including wild plants (Baerg, 1923; Shanks and Sjulin, 1988), but it also estivates outside strawberry fields. In many areas, strawberry fields are relatively small and dispersed, causing a continual genetic mixing of strawberry bud weevil from within the fields as well as from other areas.

Impact on Beneficial Insects

Strawberry is pollinated by gravity, wind, and various insects. Honey bees are important insects that pollinate this crop (Nye and Anderson, 1974; Vincent, et al., 1990). Chlorpyrifos is highly toxic to honey bees and other pollinators, and the use of this insecticide during bloom may result in severe bee losses; therefore, its use during bloom currently is not permitted (Lunden, et al., 1986). Insecticide applications can be made prior to the plant's blooming so that pollinators will not be affected.

Integrated Pest Management

Formal Integrated Pest Management (IPM) programs have not been developed in most areas. Fields are scouted to determine whether strawberry bud weevil is present, and applications of insecticides are made based on plant phenology. Economic thresholds are based on estimates of the percentage of flowers cut per meter. This provides a suitable monitoring method for large fields. An economic threshold of one cut bud per 2 linear row feet is used in New York (Schaefers, 1981), and one cut bud per 1.5 linear row feet in Massachusetts (Hauschild, 1987).

FUTURE PEST MANAGEMENT OPTIONS

If chlorpyrifos were not available for control of strawberry bud weevil on strawberry, methoxychlor or carbaryl use would increase in some States. In many States, fields currently treated with chlorpyrifos would be left untreated, or growers would rely on insecticides directed at other pests to suppress strawberry bud weevil.

SUMMARY

Chlorpyrifos effectively controls strawberry bud weevil. There are few alternatives available for controlling this insect. If chlorpyrifos becomes unavailable, either more total insecticide will have to be applied to achieve similar control, or the crop loss will be greater. If chlorpyrifos is discontinued, the amount of strawberry acreage will probably not be reduced. However, except where strawberry bud weevil populations are severe, production costs may increase and yields may decrease in areas where this insect is a major pest of strawberry. In some areas where the market is saturated (mainly pick-your-own operations), some growers will be driven out of business.

Chlorpyrifos Use on Asparagus

Susan P. Whitney

INTRODUCTION

Asparagus, *Asparagus officinalis* L., is a perennial that does not reach full production until about the fourth year after transplantation. The first 3 years in the development of an asparagus bed are devoted to preparing the field for 15 years of productive life (Schimmel, et al., 1990). Ninety-seven percent of asparagus production is concentrated in five States, as shown in Table 28.

Chlorpyrifos 4E is registered on asparagus to control the asparagus aphid, the asparagus beetle, and the spotted asparagus beetle. Chlorpyrifos 4E is also registered for control of cutworms. Common pest species are the black cutworm, the spotted cutworm, the variegated cutworm (Sorensen and Baker, 1983), the white cutworm, and the dark-sided cutworm (Grafius, 1983).

Table 28. Asparagus production in the United States, fresh market and processing, 1989

State	Acres Harvested	Value ($1,000)
California	37,500	71,978
Illinois	800	900
Michigan	23,000	14,784
New Jersey	1,500	2,462
Washington	32,000	55,074
Other States	3,710	4,424
TOTAL	98,510	149,622

Source: USDA (1990).

Chlorpyrifos 4E is applied as a broadcast foliar spray at the rate of 2 pt per acre. Application for cutworms is recommended when soil is moist and worms are active on or near the soil surface. Applications may be made during the fern stage for control of asparagus beetles and asparagus aphid when field counts or crop injury indicate that damaging pest populations are developing or present. No more than one preharvest application per season is allowed. A preharvest interval of 24 hours is required. No more than two postharvest applications are permitted during the fern stage. Chlorpyrifos 4E is used in the Midwest, Pacific Northwest, and in California and Arizona under an SLN. Other insecticides registered on asparagus for the pests mentioned above are shown in Table 29.

PEST INFESTATION AND DAMAGE

Major insect pests of asparagus are the asparagus aphid, *Brachycorynella asparagi* (Mordvilko); the asparagus beetle, *Crioceris asparagi* (Linnaeus); the spotted asparagus beetle, *Crioceris duodecimpunctata* (Linnaeus); the beet armyworm, *Spodoptera exigua* (Hubner); the asparagus miner, *Ophiomyia simplex* (Loew); and cutworms, including the black cutworm.

The asparagus aphid is specific to asparagus. Sorensen and Baker (1983) discuss life history and damage in North Carolina. Folwell, et al. (1990) discuss ecology and damage in Washington. The aphid has several generations each year;

Table 29. Insecticides registered for use on asparagus and pests controlled

Pesticide		Insect Pests			
Trade Name	Active Ingredient	Asparagus aphid	Asparagus beetle	Cutworms	Beet armyworm
Cythion 57% EC	malathion	X	X		
Di-Syston 8	disulfoton	X SLN[a]			
Lannate	methomyl		X	X	X
Lannate L	methomyl		X	X	X
Lannate LV	methomyl		X	X	X
Lorsban 4E	chlorpyrifos	X SLN[b]			X
Sevin XLR	carbaryl			X	
Sevin 80S	carbaryl		X		
Sevin 50W	carbaryl		X		
Sevin 4F	carbaryl		X		
Ambush	permethrin		X	X	
Ambush 25W	permethrin		X	X	
Ambush 25W-WSP	permethrin		X	X	
Pounce 3.2 EC	permethrin		X	X	

[a]AZ, CA, WA, MI, OR, IL, NC
[b]CA, AZ

new generations continue to be produced as long as warm, dry weather continues and host plants are available. In both States this aphid probably overwinters in the egg stage. Nymphs and adults extract sap from leaves of the host. Feeding causes a toxic reaction, producing bushy, stunted new growth (Putnam, et al., 1983). Heavily infested seedlings may shrivel and die. Similar infestations on older plants may cause dwarfing and premature release of buds destined to be the next year's spears and ferns.

Asparagus beetles are host-specific to asparagus. Sorensen and Baker (1983) discuss life history and damage in North Carolina. Adults overwinter and then attack when shoots first appear in spring. This pest feeds on shoots and leaves, and is particularly damaging when feeding on bud tips. Larvae of asparagus beetle attack spears and ferns. Larvae of spotted asparagus beetle feed on the "berries" and therefore are not a problem. Larvae of both species secrete a black fluid that stains the plant. There are two to five generations per year in Washington (Johnson, et al., 1986a).

Cutworms attack a wide variety of plants and are common throughout the United States, as reported by Sorensen and Baker (1983). These pests overwinter as larvae or pupae, depending on the species. Young cutworms climb asparagus plants and feed on spears and ferns. Mature cutworms, however, are sluggish, nocturnal, and soil-burrowing. Pupation occurs in the soil. There are two to four generations per year, depending on latitude. Grafius (1983) estimates that in Michigan an average of 3 to 5 percent of the crop is lost annually to cutworm damage. Individual fields may experience 80 to 90 percent damage.

PEST MANAGEMENT

Current Chemical Usage

The results of the National Agricultural Pesticide Impact Assessment Program (NAPIAP) pesticide use assessment survey indicate that one application of chlorpyrifos is used to treat 15 percent of the asparagus in the Midwest for cutworms. In Washington, 60 percent of the acreage is treated twice for asparagus aphid, asparagus beetles, and cutworms. There would be no estimated change in yield if chlorpyrifos were not available in Illinois. Chlorpyrifos and permethrin are both effective insecticides for cutworm control. Permethrin will provide from -5 to +20 percent of the control of cutworms when compared to chlorpyrifos. The difference is due to moisture and temperature at the time of control.

Chemical Alternatives to Chlorpyrifos

The NAPIAP survey identified constraints for use of alternative chemical treatments, as shown in Table 30.

Comparative Performance

Harris, et al. (1982) compared the effectiveness of chlorpyrifos, permethrin, and three experimental pyrethroids for cutworm control. The authors concluded that chlorpyrifos was the least toxic by direct contact to third instar darksided, black, and white cutworms. In field tests, minimal difference was noted for white cutworm mortality. Black cutworm mortality was inconclusive.

The NAPIAP survey results show that for cutworm control, permethrin use in Illinois would result in no yield change, a slight yield increase in Michigan, and a -5 to +20 percent change in Washington. Use of all other registered alternatives would cause yield reductions from 5 to 100 percent.

Nonchemical Alternatives

Burning/mowing—Halfhill et al. (1984) report that fall burning or mowing of ferns reduced aphid numbers by 65 to 76 percent and the numbers of spears infested by 13 to 56 percent. The best combination of treatments was fall mowing, followed by spring tillage. This reduced the number of fundatrices by 98 percent and the percentage of spears infested by 85 percent.

Weed control—Weed control in asparagus beds is recommended by Johnson et al. (1986a) to reduce cutworm populations. Female cutworms select weedy areas to oviposit; thus, elimination of weeds reduces cutworm pressure on the crop.

Parasites and predators—Capinera and Lilly (1975) identified a eulophid (Hymenoptera) parasite, *Tetrastichus asparagi* Crawford, which attacks the asparagus beetle. This parasite is very common and effective in reducing populations of asparagus beetle in Michigan and Massachusetts. Capinera and Lilly also identified several carabid beetles, a predaceous nabid, and a pentatomid stink bug as natural enemies of the asparagus beetle. Stary (1990) investigated the possible use of a hymenopteran parasite from Czechoslovakia to control asparagus aphid. None of these control measures are practical in today's commercial asparagus production.

Impact on Beneficial Insects

Chlorpyrifos 4E is highly toxic to bees. Johnson et al. (1986a) caution against applying any pesticides during asparagus blooming to protect honeybees and other pollinators.

Table 30. Constraints regarding use of alternative chemical treatments on asparagus

Pesticide	Constraints
malathion	Lack of performance; can be used on beetles when bees are working; no grower confidence.
disulfoton	Excellent for aphid control; less effective on other pests; must be used only after harvest.
methomyl	Fair on cutworms and beetles
carbaryl	Fair to poor on armyworms and cutworms; caution on honey bees
permethrin	Excellent on cutworms; fair on beetles; caution on honey bees

Integrated Pest Management

Johnson et al. (1986a) discuss an asparagus IPM program proposed by Washington State University Cooperative Extension and the Washington Asparagus Growers Association. Objectives of the program were to improve timing of pesticide applications and to coordinate growing practices and pest control strategies for asparagus pests. Scouts sampled for rust, asparagus aphid, asparagus beetle, cutworms, weeds, and beneficial insects. Growers used a variety of cultural practices; however, chemical control was the dominant management practice.

SUMMARY

The NAPIAP survey results show that chlorpyrifos 4E is an important management tool in asparagus production. Nationally, chlorpyrifos provides its best control in cutworm management. Disulfoton is a preferred insecticide to chlorpyrifos for asparagus aphid control after ferning. Alternative chemical and cultural control options and biological control cannot replace the pest control provided by chlorpyrifos usage in U.S. asparagus production.

Chlorpyrifos Use on Crucifers

Richard N. Story

INTRODUCTION

Chlorpyrifos 50WP is labeled for use on broccoli, cauliflower, collard, brussels sprout, cabbage, Chinese cabbage, kale, and kohlrabi for the control of the imported cabbageworm, striped flea beetle adult, aphids (cabbage aphid, turnip aphid, and green peach aphid), and cutworms (e.g., the black cutworm). Chlorpyrifos 50WP is applied as a foliar spray at a rate of 2 lb per acre, with no more than six applications per season.

Chlorpyrifos 4E is labeled for use on the crops listed above for controlling root maggots (e.g., cabbage maggot, *Hylemya brassicae* (Weidemann), and seedcorn maggot). Chlorpyrifos 4E is applied in a water-based spray at a rate that varies, depending on the crop. Chlorpyrifos 4E is also labeled for controlling the cabbage aphid, cutworms, imported cabbageworm, and striped flea beetle adults on brussels sprout.

Chlorpyrifos 15G is labeled for controlling cabbage maggots on the same plants as chlorpyrifos 4E, with one additional cruciferous crop (radish). Chlorpyrifos 15G is applied across the seed row in a 4-inch-wide band at a rate of 4.6 to 9.6 ounces per 1,000 ft of row (Meister, 1991).

Registered insecticide alternatives to chlorpyrifos are numerous for certain crops and pests, but limited for other crop-pest combinations (Table 31).

PEST INFESTATION AND DAMAGE

The diamondback moth, *Plutella xylostella* (Linneaus), is perhaps the most destructive pest of crucifers in the Eastern and Central United States due to the development of insecticide resistance to many organophosphate, carbamate, and pyrethroid insecticides (Georghiou, 1986; Tabashnik et al., 1990.) Larvae feed on the foliage of plants, causing cosmetic injury that reduces the grade of the produce or renders it unmarketable (Chalfant et al., 1979; Rice Mahr et al., 1993). Other important lepidopterous pests that are widely distributed in the United States include the cabbage looper, *Trichoplusia ni* (Hubner), and the imported cabbageworm, *Pieris rapae* (Linnaeus). Although the imported cabbageworm occurs in

Table 31. Registered insecticide alternatives to chlorpyrifos on cole crops on the (1) imported cabbageworm, (2) flea beetle, (3) cutworms, (4) aphids, and (5) root maggots

	Broccoli	Brussels sprout	Cabbage	Cauliflower	Chinese cabbage	Collard	Kale	Kohlrabi
acephate		1,2		1,2				
azinphos-methyl	1,2,5	1,2,5	1,2,5	1,2,5	1,2,5			
Bacillus thuringiensis	1	1	1	1	1	1	1	1
carbaryl	1,3	1,3	1,3	1,3	3	1,3	1,3	1,3
chlorpyrifos 4E	5	5	5	5	5	5	5	5
chlorpyrifos 15G	5	5	5	5	5	5	5	5
chlorpyrifos 50W	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4		1,2,3,4	1,2,3,4	1,2,3,4
cryolite	1,3,4		1,3,4	1,3,4		1,3		
diazinon	1,2,4,5	1,2,4,5	1,2,4,5	1,2,4,5		1,2	1.2	
dimethoate	2		2	2		2	2	
disulfoton	2,3	2,3	2,3	2,3				
endosulfan	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4		1	1,3	
esfenvalerate	1,3,4		1,3,4	1,3,4	1,3,4	1,3,4		
fonofos	5	5	5	5				
malathion	1,2	2	1,2	2		2	2	1,2
methamidophos	1,2	1,2	1,2	1,2	1,2			
methomyl	1	1	1	1		1	1	
methoxychlor	1	1	1	1		1,3	1,3	1
mevinphos	1,2	1,2	1,2	1,2		1	1	
oxydemeton-methyl	2	2	2	2	2			
naled	1,2	1,2	1,2	1,2		1,2	1,2	
parathion	1,2,4	1,2,4	1,2,4	1,2,4		2,3	2,3,4	1,2,4
permethrin	1,2	1,2	1,2	1,2	1,2	1,2		
pyrethrins	1,2,3	1,2,3	1,2,3	1,2,3		1,2	1,2	

Southern States, it is most numerous and destructive in the Northern United States and Canada (Sorensen and Baker, 1983). This pest causes damage to crucifers that is similar to the damage caused by the diamondback moth and cabbage looper. The beet armyworm, *Spodoptera exigua* (Hubner), can also be damaging to crucifers. Cabbage aphid, *Brevicoryne brassicae* (Linnaeus); turnip aphid, *Lipaphis erysimi* (Kaltenbach); and green peach aphid, *Myzus persicae* (Sulzer), are widely distributed throughout the United States. However, these pests are most numerous (as well as causing the most substantial crop losses) in the Southern States. The cabbage aphid feeds on the underside of leaves of primarily broccoli, collard, kale, and radish, causing the foliage to curl and wilt. Heavily infested plants are killed; less heavily infested plants grow slowly and may become stunted, producing a small, unmarketable product. Aphid colonies in harvested heads of cabbage, broccoli, cauliflower, and brussels sprout cannot be removed before processing or marketing and are a contaminant (Reid and Cuthbert, 1976). The striped flea beetle, *Phyllotreta striolata* (Fabricius), is distributed throughout the United States, but is most common in the Eastern and Pacific areas of the United States (Sorensen and Baker, 1983). The striped flea beetle prefers mustard, turnip, or radish, but may feed on any crucifer. The majority of damage is caused by adults chewing holes in the leaves of seedling plants. The presence of abundant beetle populations early in crop development may kill seedling plants. Cutworms, principally the black cutworm, *Agrotis ipsilon* (Hufnagel), damage crucifer crops throughout the United States and Canada (Rings et al., 1974). Several species of cutworm injure vegetable seedlings and newly set plants by cutting off young plants near the ground or by feeding on the foliage. The cabbage maggot, *Delia radicum* (Linnaeus), is most injurious to crucifer crops in the Northern United States and Canada. The cabbage maggot consumes the roots and tunnels into stems of all cruciferous crops (Sorensen and Baker, 1983). The seedcorn maggot, *Delia platura* (Meigen), is widely distributed in cool, damp growing areas in both the United States and southern Canada. This pest has a wide host range, and during cool, damp growing seasons can be very destructive to crucifer seedling plantings.

PEST MANAGEMENT

Current Chemical Usage

A NAPIAP pesticide use survey targeted the major producing State for each vegetable, providing information on current usage patterns (1987-89 average) throughout the United States. These data are summarized as follows:

Broccoli—California produces 88 percent of the more than 118,000 acres of U.S. broccoli. The remaining 12 percent is grown in production areas throughout the United States, with Texas and Arizona being the next two largest producers. The cabbage maggot is the most serious pest of broccoli production, with lepidopterous pests and aphids secondary in importance. These latter two pests are troublesome in all production areas.

Chlorpyrifos is the most widely used insecticide for cabbage maggot control in broccoli. The 15G formulation is primarily used, but 4E is also registered and used. Diazinon is second in usage to chlorpyrifos for cabbage maggot control. Chlorpyrifos 50WP is widely used for control of lepidopterous and aphid pests.

Brussels sprout—California produces 95 percent of the Nation's 3,600 acres of brussels sprout. Ninety percent of the surveyed brussels sprout acreage is treated with chlorpyrifos 15G for cabbage maggot control, and nearly 100 percent is treated with chlorpyrifos 50WP for control of lepidopterous pests, cutworms, and aphids.

Chinese cabbage—Chinese cabbage is grown on less than 9,000 U.S. acres by fewer than 250 producers. Seventy-five percent of this production is in California and Florida, with New York and New Jersey also being important production areas. According to results from the survey, chlorpyrifos 15G and 4E are used for controlling the cabbage maggot on 50 percent of the acreage in New Jersey and 20 percent in New York. Diazinon is second in usage for this pest. Chlorpyrifos 50WP is used extensively for control of lepidopterous pests on Chinese cabbage.

Head cabbage—Head cabbage is grown on more than 73,000 acres in the United States. Production is broadly distributed throughout the country. Chlorpyrifos 15G and 4E usage for root maggot control is high in California and most of the Northern States (California, 60 percent; New Jersey, 40 percent; New York, 80 percent; Washington, 100 percent). Use of this pesticide is lower in the Southern States where the cabbage maggot is not an economic pest in cabbage. Chlorpyrifos is the preferred material for cabbage maggot control. Chlorpyrifos 50WP is widely used for aphid and lepidopterous pest control in most production areas, but shares these markets with alternative insecticides. Florida reports that 40 percent of its acreage is treated with chlorpyrifos 50WP for lepidopterous pests, while New Jersey (15 percent) relies more heavily on other insecticides.

Cauliflower—California produces 75 percent of the 67,000 acres of cauliflower grown in the United States, followed by Arizona, Oregon, Washington, Michigan, and New York. In California, 75 percent of the acreage is treated for cabbage maggot, and chlorpyrifos 15G or 4E is virtually the only insecticide used. Other growing areas report a high percentage of acres treated for root maggots; chlorpyrifos 15G or 4E are the primary insecticides used. Chlorpyrifos 50WP is used on 30 percent of the acreage in both Arizona and Florida for lepidopterous pest control and on 20 percent of the acreage in California and Florida for aphid control.

Collard—Collard is grown in the Southern United States, with Georgia being the largest producer. Sixty-three percent of the U.S. production is from Arizona, Alabama, Florida, Georgia, North Carolina, and South Carolina. Because collard is grown primarily in Southern States, where the cabbage maggot is not a production pest, chlorpyrifos 15G and 4E usage is for other pests. Florida reports a high percentage of acres treated with chlorpyrifos 15G for the seedcorn maggot (70 percent). New Jersey acreage is treated equally with chlorpyrifos 15G and diazinon 14G. Chlorpyrifos 50WP is used for lepidopterous pest control in Arizona (20 percent), Maryland (1 percent), and New Jersey (7.5 percent).

Kale—Kale production is widely spread throughout the United States, with the national acreage being slightly more than 6,000 acres. The 1987 Census of Agriculture identified 670 producers. Survey results from Georgia, Maryland, and New Jersey indicate a relatively low usage of chlorpyrifos 15G and 4E for root maggots (10 percent or less), since root maggots tend to be sporadic pests in these States. Where treatments are applied, chlorpyrifos 15G and 4E are the most commonly used insecticides. Chlorpyrifos 50WP is used for aphids in Georgia (5 percent) and for lepidopterous pests in Maryland (1 percent) and New Jersey (less than 10 percent).

Kohlrabi—A minimal amount of information was available on kohlrabi production. This crop appears to have a small production nationally. Arizona reports no usage of chlorpyrifos 15G or 4E, since the cabbage maggot is not a production problem where this crop is raised. Chlorpyrifos 50WP is used on 30 percent of Arizona's acreage for lepidopterous pest control.

Chemical Alternatives to Chlorpyrifos

Chlorpyrifos is a broad-spectrum pest management tool for cruciferous vegetable production. Regarding crucifer pest management, alternative insecticides to chlorpyrifos are considerably more restricted in their spectrum, duration, and efficacy. The three formulations of chlorpyrifos allow for efficacious applications against a broad spectrum of crucifer insect pests, with minimal risk to the environment, applicator, or consumer.

The availability of chemical alternatives for controlling the imported cabbageworm, flea beetle, cutworms, aphids, and root maggots varies, depending on what products are registered on each particular crop (Table 31). Alternatives for controlling imported cabbageworm are numerous for broccoli (17), brussels sprout (14), cabbage (16), and cauliflower (16), and limited for the other crops such as kohlrabi (5), and Chinese cabbage (5). More alternatives are also available for controlling aphids, flea beetle, and cutworms in broccoli, brussels sprout, cabbage, and cauliflower than in other crops.

Few alternatives are available for control of root maggots. Azinphos-methyl, diazinon, and fonofos are the only alternatives to chlorpyrifos for controlling root maggots on broccoli, brussels sprout, cabbage, and cauliflower. Chlorpyrifos usages for root maggot control on kohlrabi, kale, and collard are critical usages for these commodities, since no registered alternatives are available for the management of this pest.

Comparative Performance

The comparative performance of chlorpyrifos to all registered alternatives on each of the crucifer crops is summarized in Tables 32 and 33. Relative efficacy (RE) is the percentage of control of a given alternative insecticide when compared to chlorpyrifos. The RE is calculated as follows:

$$RE = \frac{\text{number of insects per plant using alternative}}{\text{number of insects per plant using chlorpyrifos}}$$

RE values: <1: alternative outperformed chlorpyrifos
>1: chlorpyrifos outperformed alternative

Table 32. Relative efficacy of alternative insecticides to pest control provided by chlorpyrifos[a]

	Imported cabbageworm	Cutworms	Aphids	Striped flea beetle	Root maggots
acephate	1.4		0.2		
azinphos-methyl	1.6		0.8		
Bacillus thuringiensis	1.1				
B.t. (Dipel)	2.8				
carbaryl	1.7	2.0		1.6	
diazinon	1.9	2.0	2.3	0.4	3.7
dimethoate			0.4		
disulfoton			0.2	1.3	
endosulfan	1.6		0.9	0.8	
esfenvalerate	0.8	0.6		0.3	
fonofos					1.2
malathion	1.9		0.6		
methomyl	1.8	2.0			
methamidophos	1.2		0.5		
methoxychlor	2.6				
methyl parathion	1.9		0.9		
mevinphos	2.5		0.2		
naled	3.3		0.8		
oxydemeton-methyl			0.4		
permethrin	0.8	1.0	3.0	0.3	

[a]Relative Efficacy (RE) = number of insects (or damage) with alternative treatment divided by number of insects (or damage) with chlorpyrifos treatment. RE less than 1.0 indicates alternative is superior to chlorpyrifos. These data are obtained from articles published in Insecticide and Acaricide Tests, vol. 1-17.

Table 33. Estimated change in yield (%) with use of alternative insecticide under moderate to heavy pest pressure from imported cabbageworm, cutworms, aphids, striped flea beetle, and root maggots[a]

	Imported cabbageworm	Cutworms	Aphids	Striped flea beetle	Root maggots
acephate	0		+5(0,+10)		
azinphos-methyl	-5(0,-7)		0		-10(-5,-15)
Bacillus thuringiensis	-2(0,-2)				
B.t. (Dipel)	-10(0,-12)				
carbaryl	-5(0,-7)	-8(-12,-5)		0	
cryolite		nda		nda	
diazinon	-5(0,-7)	-8(-12,-5)	0	+2(0,+4)	-10(-5,-15)
dimethoate			+5(0,+10)		
disulfoton			+5(0,+10)	0	
endosulfan	0	nda	0	0	
esfenvalerate	0(0,+2)	0(-2,+2)		+2(0,+4)	
fonofos					0
methomyl	-5(0,-7)	-8(-12,-5)			
malathion	-5(0,-7)		0		
methamidophos	0		0		
methoxychlor	-10(0,-15)				
methyl-parathion	-5(0,-7)	nda	0	nda	
mevinphos	-5(0,-7)	nda	+5(0,+10)		
naled	-5(0,-7)		0		
oxydemeton-methyl			0		
permethrin	0(0,+2)	0	-5(0,-10)	+2(0,+4)	

[a]Estimated yield loss based on relative efficacy of alternative pesticide (Table 32), nature of damage (cosmetic *vs* indirect), and estimate of author in consultation with other vegetable entomologists.

nda = no data available

An RE value of 0.5 indicates that the alternative killed 50 percent more insects than chlorpyrifos. RE values greater than 1.0 indicate chlorpyrifos outperformed the alternative insecticide.

Aphids—Chlorpyrifos provides poor aphid control on crucifer vegetable crops when compared to registered alternatives. Acephate provided the best control overall, and was used as a standard in many insecticide efficacy tests (Tables 32 and 33). Acephate treatment plots had 20 percent the number of aphids compared to treatments of chlorpyrifos 50WP. Dimethoate, disulfoton, mevinphos, and oxydemeton-methyl had RE values of less than 0.5. Chlorpyrifos outperformed diazinon and permethrin (Table 32). In terms of yield loss due to aphids, only permethrin provided poorer control (Table 33).

Striped flea beetle—Chlorpyrifos does not perform well for controlling flea beetle on crucifer vegetable crops. In the few trials that were available, chlorpyrifos was outperformed by all alternatives except carbaryl and disulfoton (Table 32). Permethrin, esfenvalerate, and diazinon showed a positive yield change compared to chlorpyrifos (Table 33). This was related to reduced cosmetic damage.

Imported Cabbageworm —Chlorpyrifos is an excellent insecticide for controlling imported cabbageworm. Only permethrin and esfenvalerate had relative efficacy values lower than chlorpyrifos (Table 32). Estimated yield changes range from -10 percent with methoxychlor and *Bacillus thuringiensis*, to unchanged with pyrethroids, methamidophos, endosulfan, and acephate (Table 33).

Cutworms—Chlorpyrifos 4E and 15G are the most effective formulations for controlling cutworms in crucifer vegetable production (Table 32 and Table 33). Efficacy data indicate that chlorpyrifos provides more reliable cutworm control than carbaryl, diazinon, and methomyl. The pyrethroids are equivalent in efficacy to chlorpyrifos (Table 33).

Root maggots—Chlorpyrifos is the most effective pest management tool available for cabbage maggot control in crucifer vegetables (Table 32 and Table 33). The cabbage maggot is the most serious seedling pest of crucifer vegetables in most States. Fonofos is comparable to chlorpyrifos in efficacy, but is only registered on four crucifer vegetable crops (Table 31 and Table 33). Diazinon and azinphos-methyl are less effective than chlorpyrifos in control (Table 33). It is estimated that an average 10 percent loss in yield would result if diazinon or azinphos-methyl were used instead of chlorpyrifos. Equivalent yield would be expected if chlorpyrifos were replaced with fonofos. Chlorpyrifos is a critical use product on collard, kale, and kohlrabi, since no alternatives to chlorpyrifos have recently been registered. The loss of chlorpyrifos would leave growers without a treatment for root maggots. Yield loss in control plots ranged from 5 to 50 percent in crucifer field trials, with moderate to heavy cabbage maggot pressure.

Nonchemical Management Alternatives

Nonchemical alternatives are available for some crucifer vegetable pests. Chemical control, however, remains the predominant management practice in order to produce high-quality vegetable products. Damage thresholds are very low, which makes the use of alternative nonchemical management methods difficult (Edersby et al., 1992). Damage from the imported cabbageworm can be reduced somewhat with the use of partially resistant cabbage cultivars (Brett and Sullivan, 1974; Stoner, 1992). Cultural practices (such as good weed control and the destruction of crop residues) and the use of resistant varieties can reduce flea beetle damage. Cultural control practices are more limited with aphids and cutworms. Some host plant resistance to aphids has been reported in crucifers (Stoner, 1990; Zalom and Pickel, 1988). Cabbage maggot damage can be reduced by late planting or by the elimination of weeds that can serve as alternate hosts.

Pesticide Resistance

The potential for crucifer pests developing resistance to chlorpyrifos is low. Resistance to chlorpyrifos has not been observed in populations of the imported cabbageworm, cabbage aphid, striped flea beetle, black cutworm, or root maggot.

Integrated Pest Management

Considerable research has been conducted over the years on management of the lepidopterous pest complex on crucifers, especially cabbage. Sampling methods have been developed, and treatment thresholds established, for the imported cabbageworm, diamondback moth, and cabbage looper (Green, 1972; Ladd et al., 1981; Workman et al., 1980). Implementation of these IPM systems has improved producer crop management systems and reduced unnecessary applications of insecticides. Sampling procedures and thresholds have also been developed for aphids (Weber et al., 1991; Hoy, 1991). However, cutworm and root maggot populations are difficult to monitor, and preventive insecticide treatments are often used. There is very low tolerance for damage in crucifer vegetable crops. Growers rely on insecticides to prevent yield loss or downgrading.

Management systems incorporating biological, cultural, or other forms of control are generally not used commercially. However, *Bacillus thuringiensis* has become widely accepted by growers, and is used in the control of lepidopterous pests in combination with insecticides. The diamondback moth has developed resistance to many organophosphate, carbamate, and pyrethroid insecticides (Georghiou, 1986). To reduce resistance development, chlorpyrifos is used in an insecticide rotation system for managing diamondback moth and beet armyworm. IPM presently has limited applications to commercial crucifer vegetable production, but there is a developing understanding of the need for (and application of) pest population monitoring, nonchemical management options, and resistance management.

FUTURE MANAGEMENT OPTIONS

The nearly prohibitive cost of developing new insecticides, as well as the increased awareness of environmental issues, limit the potential for the registration of new pesticides. Crucifers are a minor use crop, with comparatively small acreage; because of this fact, the potential for recovering the considerable expense of new product registrations is small. Although new formulations of *Bacillus thuringiensis* show promise for controlling lepidopterous pests, the outlook for development of biological agents to control soil insects pests is limited. For the near future, vegetable growers will need insecticides to produce the high-quality crucifers that consumers have come to demand.

SUMMARY

A high percentage of crucifer vegetable acreage in the United States receives insecticide application for controlling root maggots, the lepidopterous pest complex, and aphids. Chlorpyrifos is the most efficacious insecticide available for root maggot management. Chlorpyrifos is used on more than 90 percent of the treated acreage. Diazinon, fonofos, and azinphos-methyl share the remaining 10 percent of the market. Diazinon and azinphos-methyl are not as effective as chlorpyrifos, and yield losses of 5 to 15 percent would be expected if these insecticides were used instead of chlorpyrifos. Fonofos provides better cabbage maggot control than diazinon, but fonofos is registered only for four cruciferous vegetables. If chlorpyrifos were not available, fonofos would be the alternative insecticide for broccoli, brussels sprout, cabbage, and cauliflower. Yield loss is difficult to estimate, but would be minimal with fonofos as a replacement for chlorpyrifos. With Chinese cabbage, azinphos-methyl is the only alternative to chlorpyrifos, and is less effective for root maggot control. However, the loss of chlorpyrifos on collard, kale and kohlrabi would leave growers without a registered chemical for root maggot control.

Chlorpyrifos 50WP is labeled for controlling the imported cabbageworm, aphids, cutworms, and striped flea beetle. Efficacious alternative insecticides are available for these pests; however, all of these alternatives are more restricted than chlorpyrifos in the spectrum, duration, and efficacy of crucifer pest management that these chemicals provide. Alternative management options to chlorpyrifos are few. Chlorpyrifos is very effective for cutworm control, with only the pyrethroids demonstrating comparable efficacy. With aphids and flea beetles, many other products are available as alternative pesticides. Chlorpyrifos 50WP is an important insecticide in a number of States for controlling the diamondback moth and beet armyworm on cruciferous vegetables.

Chlorpyrifos Use on Mint

John Rinehold and Jeffrey J. Jenkins

INTRODUCTION

Approximately 90,000 acres of mint were harvested in 1988-89 in the United States. About 80 percent is grown in the Pacific Northwest. The remaining 20 percent of the acreage is grown in the Midwest (Indiana and Wisconsin).

The Pesticide Label Information Retrieval System (PLIRS) contains label information for pesticides registered in the Pacific Northwest (Washington, Oregon, and Idaho). Table 34 is the PLIRS list of insecticides registered on mint as of May 1992. This list also includes alternative insecticides for certain usages should chlorpyrifos be discontinued. For chlorpyrifos usage details, see Figure 25.

PEST INFESTATION AND DAMAGE

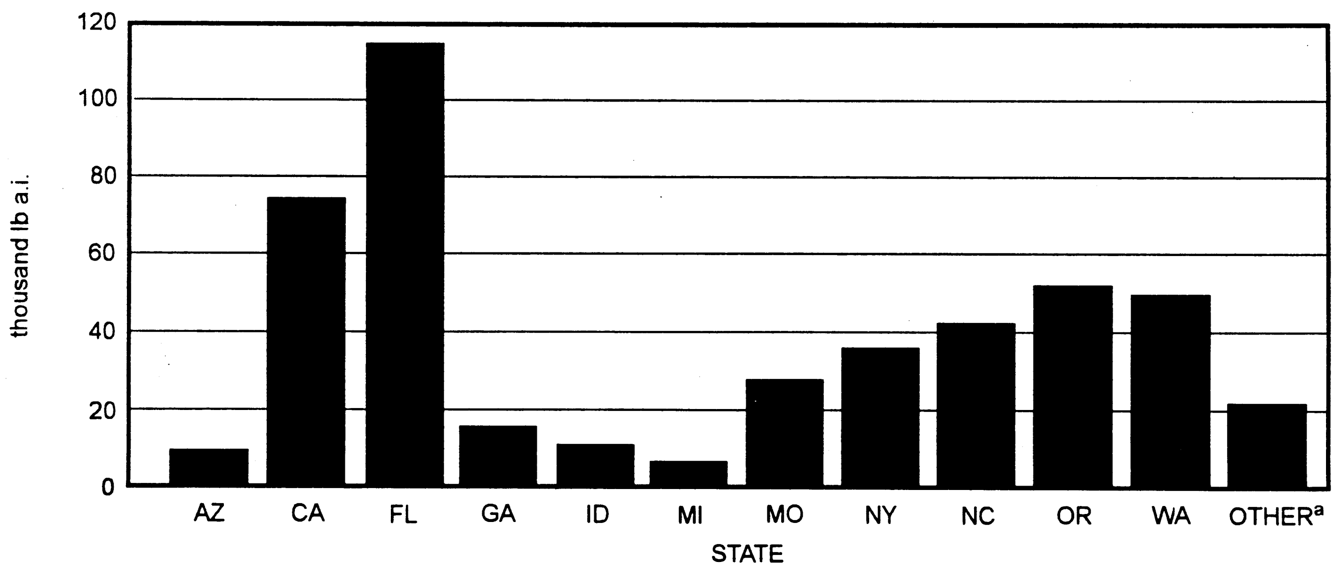
Several cutworms cause extensive damage to mint. The redbacked cutworm, *Euxoa ochrogaster* (Guenee), is a major pest in central Oregon and occasionally a problem in Washington. This cutworm feeds on roots and rhizomes of mint at or beneath the soil surface from April through June. Even low populations of redbacked cutworm will significantly reduce plant vigor or kill plants, especially in new plantings (Danielson and Berry, 1978). Climate, as well as other conditions, influence the intensity of infestations of the redbacked cutworm. Hot, dry conditions in August promote adult moth survival and ensure a higher egg-laying capacity.

Berry (1975) calculated oil yield loss due to redbacked cutworm for the 1973 season (Table 35). Danielson and Berry (1978) provided biological data and calculated the economic injury levels (EIL) for the redbacked cutworm. They were able to calculate an EIL only in newly planted mint fields. For vigorously growing mint fields that were least 6 years old, no EIL could be established because no correlation was found between cutworm density and oil yield.

The variegated cutworm, *Peridroma saucia* (Hubner); spotted cutworm, *Xestia* spp.; and western yellowstriped armyworm, *Spodoptera praefica* (Grote) primarily consume leaves and buds of mint from mid-July through August. Berry and Shields (1980) provide biological data and calculated the EIL for the variegated cutworm in their studies in the Willamette Valley of Oregon. Their work documented the tremendous potential that exists for damage by mature cutworm when they found that fifth and sixth instars consume 94 percent of the total foliage during this insect's development.

The garden symphylan, *Scutigerella immaculata* (Newport), is a severe pest on mint in the Willamette Valley and an occasional pest in central Oregon and Washington. This pest is becoming increasingly important in other parts of Oregon. The garden symphylan is a soil-inhabiting general feeder that attacks plant roots and any plant parts that are in contact with the soil. This pest is most active in the warm soil of the spring and summer. Fine-textured soils with high organic matter content are conducive to population buildup of symphylan. Sym-

Figure 25. Chlorpyrifos 4E and 50WP Use on Mint, 1987-89 Average [Total: 459,963 lb a.i.]



[a]Other: AL,DE,IL,LA,MD,MS,NJ,OK,SC,SD,TX,UT,VA,WV,WI

Table 34 —Insecticides registered on mint, rates applied, and number of labels available, derived from PLIRS and from the *PNW Insect Control Handbook*. All chemicals are applied by ground equipment.

Pest	Chemicals Registered	Rates Applied	Labels
cutworms	chlorpyrifos 4E	1 - 2 lb/acre	1
	acephate 75S	1 lb	1
	fonofos 10G	4 lb	1
	B.T.	1 - 3 quarts	3
	Javelin WG		
	Dipel 2X WP		
	malathion	0.9 lb	4
	Drexel Malathion 5 EC		
	Prentox 5 EC		
	Micro-Flow Malathion 5 EC		
	Cythion Insecticide 57 EC		
	methomyl	0.9 lb	3
	Nudrin 1.8		
	Nudrin 90 S		
	methomyl L		
symphylans	chlorpyrifos 4E SLN	2 lb	1
	metam-sodium	40 - 100 gal	11
	Nemasol Soil Fumigant		
	Simplot Metam		
	Amvac Metam-sodium		
	Riverside/Terra Vapam		
	Setre Metam-sodium		
	ICI Vapam		
	Or-Cal Sectagon II		
	Platte Metam		
	fonofos 10G	2 lb	4
	fonofos 10G		
	fonofos 4E		
	dichloropropene + chloropicrin	18 gal	7
	Telone C-17		
	Telone II		
	Tri-Form 30		
	Tri-Form 15		
mint root borer	chlorpyrifos 4E	2 lb	1

Table 35. Decrease in oil yield as related to larvae density[a]

Number of Larvae/sq ft	Oil Yield (lb/acre)	Percent Reduction
0	21.11	na
2	21.30	<1.0
4	18.80	10.9
6	12.28	41.8
10	0	100.0

[a]Source: Berry, 1975

phylan populations reduce mint yield in newly planted fields and can destroy the entire stands (R.E. Berry, G. Fisher, M. Morris, 1991, personal communication). The symphylan feeds on the fine roots of mint. Plant symptoms due to symphylan feeding include stunting, slow growth, and plant death.

Although no calculated EIL exists for symphylan on mint, when levels of 5 symphylans per shovelful of soil are found, oil yields often are reduced.

The mint root borer, *Fumibotys funalis*, is an important pest in Washington, Oregon, and Idaho. This borer does not occur in central Oregon, but is a serious pest in the Willamette Valley, the Yakima Valley, and Idaho.

From mid-July to late October the mint root borer weakens the mint plants by feeding within the rhizomes, making these plants susceptible to winter injury and damage from the cultural disease control practice of flaming. Although damage from the mint root borer is localized within fields, the larval infestation can move from rhizome to rhizome, spreading the infestation. Mint rootstock contaminated by the mint root borer is the major means by which borers infest fields, since the moth is a poor flyer (Morris, 1990, personal communication).

Table 36. Three-year average for chlorpyrifos and alternative chemical use

Chemical	Percent Fields Treated	Primary Target Pest	Impact if chlorpyrifos were not available and a substitute was used: Region	Percent Yield
chlorpyrifos 4E	70	Mint root borer	Willamette Valley	-25 to -40
	30	Redbacked cutworm	Central Oregon	-10
	—	Garden symphylan	Willamette Valley	-10
chlorpyrifos 4E	14	Mint root borer	Yakima Valley	-10 to -20
		Cutworms	Yakima Valley	—
chlorpyrifos 4E	35	Mint root borer	Idaho	-25 to -35
chlorpyrifos 4E	—	Variegated cutworm	Indiana	—
methomyl L.	—	Variegated cutworm	Indiana	0
acephate 75S	—	Variegated cutworm	Indiana	0
chlorpyrifos 4E	30	Variegated cutworm	Michigan	0
methomyl L.	30	Variegated cutworm	Michigan	0
malathion 5E	5	Variegated cutworm	Michigan	0
acepahte 75S	—	Variegated cutworm	Michigan	0

Source: This table is a compilation of survey information obtained from R.E. Berry, Oregon State University; Mark Morris, A.M. Todd Company; Rick Foster, Purdue University; and Ed Grafius, Michigan State University.

PEST MANAGEMENT

Current Chemical Usage

Chlorpyrifos and other chemical treatments are used to control cutworms, symphylan, and mint root borer in the Pacific Northwest and the Midwest. Table 36 depicts the 3-year average for chlorpyrifos and alternative chemical treatments in these regions.

Chemical Alternatives to Chlorpyrifos

Insecticides registered for treating pests on mint are listed in Table 34. The only insecticide registered for controlling the mint borer is chlorpyrifos. Dichloropropene plus chloropicrin combinations and metam-sodium are registered for controlling garden symphylan; however, these chemicals are soil fumigants registered for preplant applications only. These chemicals are acceptable alternatives for field preparation, though they have no utility in established stands or in newly planted fields where symphylans are imported by equipment or by contaminated root stocks.

Fonofos 10G and 4E are viable alternatives to chlorpyrifos for garden symphylan control, but Dyfonate 10G will not be reregistered for this usage. Fonofos is not compatible with terbacil, the most important herbicide used on mint. The simultaneous application of terbacil and fonofos will cause severe phytotoxicity to mint. Chlorpyrifos is not the most efficacious product for controlling garden symphylan; however, by rotating chlorpyrifos with fonofos, growers can reduce the onset of possible resistance.

Products containing the bacteria *Bacillus thuringiensis* and malathion have registrations on mint but are not recommended for control of cutworms because of their limited efficacy. The mint registration of malathion will not be pursued in reregistration. For variegated cutworm and cutworms other than the redbacked cutworm, methomyl and acephate are viable alternatives to chlorpyrifos. Acephate is most effective on later instars, while methomyl is most effective on early instars. Chlorpyrifos is not used to control foliar cutworms and loopers in July and early August because there is a 90-day preharvest interval for foliar applications.

Chlorpyrifos is the preferred chemical for controlling the redbacked cutworm, which feeds at or beneath the soil level. Dyfonate 10G is an alternative, but mint is being removed from the label. Acephate is a recommended alternative for the redbacked cutworm; however, chlorpyrifos has a longer residual and is more effective under cool conditions. Acephate is restricted by labeling to two applications per season. Multiple insecticidal applications throughout the season are required: to control the redbacked cutworm in spring, the root weevil adults in June, and loopers and foliar cutworms in the late summer. Since acephate may only be applied twice, an early-season treatment of chlorpyrifos for redbacked cutworm control would allow for the later season's foliar usage of acephate.

Comparative Performance

Chlorpyrifos is the only registered insecticide for the mint root borer. Pike (1978) showed that chlorpyrifos, used as a broadcast treatment, effectively reduced mint borer populations when incorporated into the soil.

Fonofos 10G and acephate 75S are effective chemical alternatives to chlorpyrifos 4E for certain pests as demonstrated by Pike (1978) and Berry (1975, 1977). Certain limitations affect both fonofos and acephate. The fonofos 10G label requires its application 3 weeks prior to an application of terbacil in order to avoid a severe phytotoxicity. Acephate's effectiveness against redbacked cutworm is reduced if the cutworm does not feed within 24 hours of application, because acephate has a short biological activity period. Fonofos is the only chemical alternative to chlorpyrifos that will control garden symphylan in an established mint field. Chlorpyrifos reduced symphylan populations in mint by 65 percent (Morris, M. 1987, unpublished data).

Nonchemical Alternatives

In western Oregon, plowing and disking mint in the fall or spring can reduce the survival of root borer adults by more than 80 percent. Because of the high fecundity of the mint root borer, however, 80 percent control may not be sufficient to prevent crop damage. (Takeyasu, et al., 1990, unpublished data). Fall or spring plowing of 10 to 14 cm deep in peppermint fields significantly reduced emergence of adult mint root borers. Disking also reduced the mint borer adult emergence (Talkington and Berry, 1986). However, plowing and disking are recommended only once every 4 years, and only in fields with a low incidence of verticillium wilt, which can be spread by these practices.

Pike and Glazer (1982) demonstrated that strip rotary tillage was a useful practice to reduce mint root borer populations in Washington. This type of tillage, which consists of alternating strips of tilled and nontilled mint, reduced adult root mint borer emergence by 79 percent in March 1980 and by 83 percent in March 1981.

In eastern Washington, strip tillage alone does not adequately control the mint root borer. Strip tillage is recommended in combination with chlorpyrifos treatment, because this method provides approximately 90 percent control (Pike, 1978). Morris, et al. (1990, unpublished), in a field study in the Yakima Valley, found that split center treatments provided 100 percent control of the mint root borer under these test conditions. These results agreed with those of Pike (1978). Under this practice, chlorpyrifos 4E is banded across peppermint. The untreated strip is plowed, then turned over on top of the treated strip, covering the chlorpyrifos. This practice improves efficacy. It also creates a new furrow for irrigation and a new hill out of the old furrow.

Integrated Pest Management

Pest monitoring is an important component of an Integrated Pest Management (IPM) program. Different field sampling techniques are used to assess whether chemical treatments are necessary on mint and are used to determine the need for control of the mint root borer, redbacked cutworm, variegated cutworm, and garden symphylan. Variegated cutworm populations are sampled with a sweep net and ground searches, and the redbacked cutworm is sampled by sifting soil samples through a series of screens. The mint root borer requires an initial sampling to assess adult moths, followed a month later by soil sampling. If the root borer EIL (approximately 2 larvae per square ft) is reached, a recommendation is made to apply chlorpyrifos in a broadcast treatment.

FUTURE PEST MANAGEMENT OPTIONS

Berry, et al. (1990) demonstrated that parasitic nematodes injected into the sprinkler irrigators and applied in Willamette Valley fields may provide control of the mint root borer. Treated plots showed 1.5 dead and 0 live mint root borers per square ft, while untreated plots averaged 2.6 live mint root borers per square ft 15 days after application. This study demonstrates that parasitic nematodes injected through sprinkler irrigation significantly reduce mint root borer populations; however, treatment cost of $300 per acre makes it impractical.

In research trials, ethoprop shows some promise as a chemical alternative to chlorpyrifos for control of some pests. Field trials conducted by Fisher and Morris (1987) indicated that ethoprop at 3 and 6 lb per acre reduced mint root borer by 57 and 60 percent, respectively. Fisher and Morris (1987), also obtained 98.9 percent control of the garden symphylan in the Willamette Valley using ethoprop at 3 lb per acre.

SUMMARY

Mint oil production in the Willamette Valley may decrease by nearly one-half million lb 1 year after chlorpyrifos is removed from the market. Similar decreases are expected in Washington and Idaho, where the mint root borer is also a severe problem. In the Willamette Valley, about 30 percent of the acres could be taken out of production by the end of the first year. Other slightly infested fields would be removed from mint production in the years following as the mint borer increases in population. Without controls, insect populations will increase rapidly once a field is infested. Verticillium wilt will increase in all areas where cultivation is used to lower mint root borer populations. Without chlorpyrifos to control the redbacked cutworm in central Oregon, production may decline by as much as 35,000 lb of oil the first year. By using acephate two times a season (to be applied no more than twice a year—just once for root weevils and once for the redbacked cutworm) partial control can be maintained.

Chlorpyrifos is an important insecticide in mint production. Critical aspects of chlorpyrifos uses in mint production are: (1) it is the only insecticide registered for control of the mint root borer, (2) it is the most effective soil-applied insecticide for redbacked cutworm control, (3) its impact as a management chemical in IPM programs on mint is significant, and (4) it is an important chemical to be maintained for rotation of insecticides on crops to prevent resistance.

Chlorpyrifos Use on Root, Tuber, and Bulb Vegetables

John C. Palumbo

INTRODUCTION

Chlorpyrifos is registered for use on onion, *Allium cepa* (L.); turnip, *Brassica rapa* L.; and radish, L. *Raphanus sativus* to control root maggots. The larvae of the cabbage maggot and turnip maggot attack the roots of cruciferous crops, *Brassica* spp. and radish, while larvae of the seed corn maggot, the onion maggot, and *D. florilega* (Meigen) attack the roots of onions. In addition, chlorpyrifos is registered for use on sweetpotato, *Ipomoea batatas* (L.), to control wireworm larvae, flea beetle, and the sweetpotato flea beetle. Two formulations of chlorpyrifos are available for use on these crops—15G and 4E. The granular formulation is applied either by placing the granules in the seed row at planting or by incorporating the granules into the soil before planting. For 15G usage details, see Figure 26. The 4E formulation is used by applying a banded spray or soil drench at planting, transplanting, or postplanting.

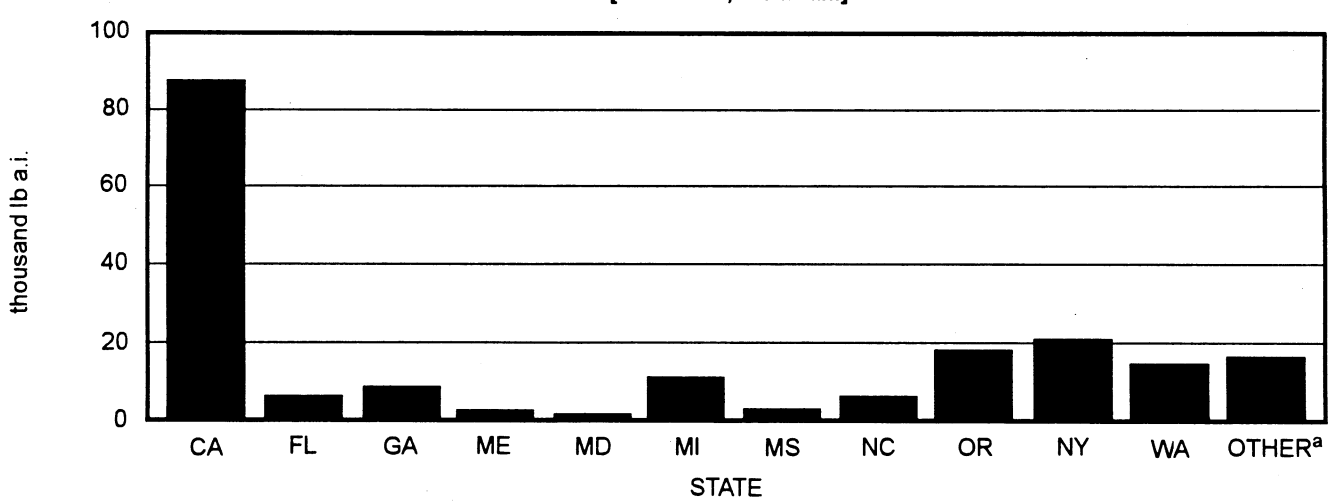
PEST INFESTATION AND DAMAGE

Primary Pests

Damage to roots and bulbs caused by the larvae of root maggots varies with geographic location, cultivar, soil conditions, and cultural practices (Finch, 1989). Cabbage maggot, *Delia radicum* (Linnaeus); onion maggot, *Delia antiqua* (Meigen); and turnip maggot, *Delia floralis* (Fallen), are restricted largely to the temperate growing areas of the Northeastern and Northcentral United States. The population biology and ecology of these insects have been well documented (Eckenrode and Chapman, 1972; Sears and Dufault, 1986; Liu et al., 1982). In general, eggs are oviposited in the soil near the base of selected host plants; larvae feed on the roots and bulbs of the plants. As a result, soil type and moisture may influence ovipositing females and result in damage. Unprotected seedlings are often damaged severely by root maggots, resulting in losses ranging from 40 to 80 percent reduction in stand (Finch et al., 1986). More mature, vigorous crops can support large populations of larvae without showing signs of attack. However, parts of the plant used for human consumption can be reduced in quality even by small populations of root maggots (Wheatly and Thompson, 1981). The most commonly used control method for preventing damage by root maggots is the use of soil insecticides applied at seeding and transplanting (Finch et al., 1986).

Production of high-quality sweetpotato in the United States is limited by a complex of soil insects consisting of wireworms, *Conoderus* spp.; southern corn rootworm, *Diabrotica undecimpunctata howardi* Barber; and *Systena* flea beetles. This group is commonly known as the WDS complex. Larvae of this complex feed on the surface of expanding roots, causing holes, scars, tunnels, and other blemishes, which result in reductions of grade and marketability (Thompson and Hurley, 1989). The severity of damage is primarily influenced by variations in soil moisture, cropping sequences, variety, and species present (Chalfant et al., 1990). The species within the WDS complex vary substantially with respect to life cycle and vertical and horizontal soil distribution (Cuthbert, 1967; Cuthbert and Reid, 1965). Accordingly, growers in the United States depend heavily on insecticides incorporated into the soil to produce damage-free crops.

Figure 26. Chlorpyrifos 15G Use on Vegetables, 1987-89 Average [Total: 199,705 lb a.i.]



[a]Other: CO,DE,ID,IL,IN,IA,LA,MO,NJ,OK,SC,SD,TN,TX,WV,WI

Secondary Pests

Crop hygiene and soil temperature are major factors in the establishment of the seed corn maggot, *Delia platura* (Meigen), in onion. This saprophagous fly oviposits alongside decaying plant material, including onions damaged by onion maggot, and slow-germinating seed (Barlow, 1965). Of secondary importance to sweetpotato are the sweetpotato flea beetle, *Chaetocnema confinis* (Crotch), and whitefringed beetles, *Graphognathus* spp. Their biologies and distributions are similar to the WDS complex (Cuthbert, 1967).

PEST MANAGEMENT

Current Chemical Usage

The responses to a NAPIAP pesticide use questionnaire reflect current usage of chlorpyrifos and chemical alternatives on 11,517 acres of radish, 1,218 acres of turnip, 49,898 acres of onion, and 61,503 acres of sweetpotato. The results of this survey are presented in Tables 37-40.

Table 37. Total chemical usage (chlorpyrifos and alternative chemicals) in U.S. sweetpotato production

State	Area Planted *(acres)*	Area Treated *(acres)*	Area Treated *(percent)*
California	7,100	7,100	100
Florida	1,100	880	80
Georgia	4,800	4,800	100
Louisiana	19,000	12,350	65
Maryland	960	960	100
Mississippi	4,000	2,520	63
New Jersey	2,300	1,840	80
North Carolina	35,300	25,063	71
South Carolina	3,300	3,300	100
Tennessee	700	175	25
Texas	7,800	1,615	21
Virginia	900	900	100
Total	87,260	61,503	70

Table 38. Total chemical usage (chlorpyrifos and alternative chemicals) in U.S. onion production

State	Area Planted *(acres)*	Area Treated *(acres)*	Area Treated *(percent)*
Arizona	1,200	1,200	100
Florida	900	815	90
Georgia	4,800	3,840	80
Idaho	7,700	7,623	99
Michigan	8,300	8,300	100
New York	13,100	13,100	100
Oregon	5,500	5,500	100
Utah	1,900	1,900	100
Washington	7,400	7,400	100
Wisconsin	1,500	225	15
Total	52,300	49,903	95

Table 39. Total chemical usage (chlorpyrifos and alternative chemicals) in U.S. radish production

State	Area Planted *(acres)*	Area Treated *(acres)*	Area Treated *(percent)*
Colorado	140	105	75
Michigan	6,000	5,400	90
New York	800	800	100
Oregon	400	400	100
Washington	4,812	4,812	100
Total	12,152	11,517	95

Table 40. Total chemical usage (chlorpyrifos and alternative chemicals) in U.S. turnip production

State	Area Planted *(acres)*	Area Treated *(acres)*	Area Treated *(percent)*
Michigan	500	500	100
New Jersey	220	198	90
Oregon	350	350	100
Washington	170	170	100
Total	1,240	1,218	98

The cancellation of chlorpyrifos for use on root, tuber, and bulb vegetables would have a significant impact on yield of these crops in some States. Commodities such as radish and turnip lack chemical alternatives for root maggot control.

Chemical Alternatives to Chlorpyrifos

Registered chemical alternatives to chlorpyrifos differ slightly among the various vegetable crops. Diazinon and fonofos are registered for cabbage maggot control, but usage of these chemicals varies according to geographic location. Alternative chemicals for onion maggot control include diazinon, ethion, and malathion. In addition, permethrin is registered for control of adult onion maggot. Ethoprop and diazinon are alternative chemicals registered for use in sweetpotato.

Few chemical alternatives are available for suppression of root maggots in root, tuber, and bulb crops. The insecticides registered to control the larvae of root maggots include chlorpyrifos, diazinon, and fonofos. Cooperative Extension Service recommendations in most States advise growers to apply treatment as granules or liquid formulation in bands, drench, or broadcast before or during seeding or transplanting. Usually one application is used in a single crop. In a few States, some commodities have no alternatives to chlorpyrifos for controlling root maggots (i.e., for turnips in Michigan and Oregon, for radishes in Colorado, and for onions in Georgia).
In areas where the onion maggot completes more than two generations in a growing season, midseason applications of insecticide are sometimes effective in controlling adult flies of the second and third generations (Liu et al., 1982). Spray applications can then be timed for peak fly activity (Wyman et

al., 1977). Three insecticides are registered for use in this manner: diazinon, malathion, and permethrin. However, recommendations for onion maggot adulticide sprays do not make allowances for adult movement in and out of fields. Producers not utilizing information on peak fly activity often make scheduled applications (Andaloro et al., 1984). Further analysis suggests that application of foliar adulticides may be unwarranted (Finch et al., 1986).

Insecticides registered for sweetpotato are available for control of the WDS complex and sweetpotato flea beetle. These insecticides include granular and liquid formulations of chlorpyrifos (at planting only), ethoprop, and diazinon. Labeled insecticides at the present time have relatively short residuals, and control is influenced by formulation, method of incorporation, and soil conditions (Getzin, 1985; Chalfant et al., 1990). Applications can be broadcast; preplant incorporated over the entire field; banded over newly seeded beds; or applied in furrow before transplanting. In the Southeastern United States, a second insecticide application banded over the row at root enlargement is often used to control late infestations, but irrigation is recommended for activation and incorporation (Chalfant et al., 1990). Chemigation with EC formulations has been evaluated, but provided generally less protection than preplant granular applications (Chalfant et al., 1987).

Comparative Performance

Based on root ratings and damage estimates, chlorpyrifos is one of the most efficacious soil insecticides for controlling root maggots in root, tuber, and bulb vegetables. In onions, granular formulations of chlorpyrifos and fonofos consistently provided significant control of the onion maggot (Grafius et al., 1990; Grafius et al., 1988; Bishop et al., 1989; Johnson and Bishop, 1987; Robbins et al., 1990). In cruciferous crops, chlorpyrifos was significantly more efficacious than fonofos for control of the cabbage maggot (Robbins et al., 1988; Robbins et al., 1983).

In the Southeastern States, chlorpyrifos incorporated at transplanting has consistently provided control of the WDS complex (Chalfant et al., 1987; Snell et al., 1987; Sorenson and Kidd, 1990; Day, 1979). Alternative granular and liquid insecticides such as diazinon and Mocap are not as effective in controlling these soil insects (R.A. Chalfant, 1991, personal communication).

Nonchemical Alternatives

Proper cultural management can help reduce or eliminate sources of root maggot infestations. Onion bulbs damaged during harvest and left in fields can provide a major source of onion maggot populations (Finch and Eckenrode, 1985). To prevent the buildup of large overwintering populations of onion maggot, damage to bulbs during harvest should be avoided (Eckenrode and Nyrop, 1986). In addition, overwinter survival of cabbage maggot can be reduced by plowing infested fields in early winter rather than in the spring (Finch and Skinner, 1980). However, these management practices do not usually eliminate the need to use soil insecticides for root maggot control. Crop rotation in small growing areas, in conjunction with late-season cultural practices, is considered a feasible supplement to chemical control of onion maggot.

Cropping sequence has been shown to influence the abundance of wireworm species in sweetpotato. *C. scissus* is more abundant following peanut; Gulf wireworm, *C. amplicollis* (Gyllenhal), is greater when following corn; and *C. rudis* is attracted to weeds (Chalfant et al., 1990). Thus, selection of fields and crop rotations should be considered in WDS pest management programs. Deep plowing may also have an adverse effect on wireworms by exposing these insect pests to predators and other natural stresses.

Another alternative to insecticides is the development of insect-resistant cultivars. Despite efforts in this area, cultivated cruciferous or onion cultivars have shown little resistance to attack by root maggot. Therefore, the development of these cultivars cannot replace the need for chemical control at this time (Finch, 1989). Plant breeders have had more success with sweetpotato. In 1966, a mass selection breeding program was initiated to develop acceptable breeding clones with resistance to insects (Jones et al., 1976). The protocol used for mass selection for resistance to sweetpotato insects has resulted in the development of eight breeding clones and six cultivars with multiple resistance to the WDS complex (Jones et al., 1989). However, commercial cultivars (e.g., "Jewel") resulting from this program have shown only moderate levels of resistance to wireworm damage (K. Sorenson, 1991, personal communication).

Pesticide Resistance

Because few registered insecticide alternatives are available for control of root maggots, the potential for pest resistance is apparent. The onion maggot developed cyclodiene resistance quickly (Harris, 1977) and has demonstrated resistance to organophosphate and carbamate insecticides as well (Harris and Svec, 1976; Harris et al., 1982). Adult onion maggot from most areas of upstate New York is already more resistant to chlorpyrifos (17-fold) than a susceptible laboratory strain (Finch et al., 1986). This most likely has occurred because of the mid-season application of organophosphate sprays to control adult flies and probably not as a consequence of soil application at seeding or transplanting.

Integrated Pest Management

The use of IPM strategies for root maggot control based on scouting, trapping, and predictive models varies with species and commodity. Considerable effort has been made to predict onion and cabbage maggot emergence patterns and peak emergence with accumulated thermal unit models (Eckenrode et al., 1975; Wyman et al., 1977). These data, used in conjunction with sticky traps (Vernon et al., 1989), have been suggested as a means of timing midseason insecticide applications for adult flies (Finch, 1989). Although accurate sampling methods have been developed for immature maggots infesting roots, most of these sampling methods are inappropriate for use in commercial production (Wilson, 1985). Because first-generation maggots are most damaging at seedling emergence, the majority of producers in North America and Canada apply a prophylactic granular insecticide at planting (Finch et al., 1986).

Several baiting techniques have been evaluated in sweetpotato for the development of wireworm sampling (Chalfant et al., 1990). Performance of these baits varied with species and time of placement in field (Doane, 1981). However, preventive applications of soil-incorporated insecticides at planting and use of resistant cultivars are currently the standard pest management practices in sweetpotato production.

FUTURE PEST MANAGEMENT OPTIONS

The extent to which the chemical industry is actively developing new insecticides for registration and use in crucifers, onion, and sweetpotato is unknown. Recent studies have indicated, however, that an insect growth regulator, cyromazine, was effective in controlling onion maggot in field studies (Hayden and Grafius, 1990). Cyromazine may have potential as a management tool for resistant populations of onion maggot or in a resistance management program because of this compound's novel mode of action.

However, most pest management practitioners emphasize that reducing the amount of active ingredient per application is an achievable management goal. This would include the development of granular applicators that can improve placement of insecticide into the soil (Suett, 1987). It is likely that the amount of insecticide needed to protect some crops against root maggots can be reduced in the near future by film-coating the seed with an insecticide (Suett and Thompson, 1985).

Nonchemical alternatives, such as biological control, are potential management tools for use in pest management systems for both root maggots in crucifers and onions and WDS complex in sweetpotato. Entomopathogenic fungi, *Beauveria bassinia*; nematodes, *Steinernema* spp.; and several parasitoid species offer potential biological control against root maggots (Carruthers and Haynes, 1986; Morris, 1985; Tomlin et al., 1985). In addition, recent development of *Bacillus thuringiensis* strains that are toxic to coleoptera, and improved strains of entomopathogenic fungi, may ultimately be integrated into wireworm management programs. However, it may be several years before these agents can be used successfully in commercial production.

A variety of physical control methods have been used to control cabbage maggot in the past. These include physical barriers to egg-laying adults such as cheesecloth frames, tar-paper squares around the base of plants, and baited traps to attract adults (Glasglow, 1924). Reemay spun polyester row-covers show promise as a potential means of excluding cabbage maggot from crops. Control of maggots with row-covers was shown to be comparable to that obtained with diazinon at planting (Matthews-Gehringer and Hough-Goldstein, 1988).

SUMMARY

The cancellation of chlorpyrifos would have a significant impact on onion and cabbage production in the Northeastern United States, where root maggot infestations occur. Few alternative insecticides provide adequate control of these pests, especially in States such as New York, Michigan, and Washington, which would most likely suffer significant losses in production. Nonchemical alternatives are not presently adequate to efficiently control root maggots. Similarly, chlorpyrifos cancellation for use in sweetpotato would have a major impact in the Southeastern United States because of the lack of viable IPM alternatives.

Chlorpyrifos Use on Rutabaga

Susan P. Whitney

INTRODUCTION

Rutabaga, *Brassica napobrassica* Linnaeus, is a crop that requires a long, cool growing season. In Wisconsin, it is planted in June and not harvested until October (Libby et al., 1974). Production is limited to the northern Midwest States and the Pacific Northwest. Michigan averages 100 acres in rutabaga production; Washington, 50 acres; and Oregon, 450 acres.

Chlorpyrifos 4E and 15G are registered on rutabaga to control the cabbage maggot. This is a critical usage on a minor crop, since no other insecticides are registered on rutabaga for control of the cabbage maggot.

Chlorpyrifos 4E is applied at the rate of 1.6 to 3.3 oz per 1,000 linear feet of row. This chemical is applied as a 4-inch band over the row at planting time so as to achieve a shallow incorporation. Restrictions prohibit applying more than 4 1/2 pints of chlorpyrifos 4E per acre and making more than one application per season. Rutabaga tops must not be used for food or feed.

Chlorpyrifos 15G is applied at the rate of 7 1/2 lb per acre to crops planted in 40-inch rows or 15 lb per acre to crops planted in 20-inch rows. Chlorpyrifos 15G is applied in a manner that will achieve shallow incorporation. Restrictions prohibit applying more than 15 lb of chlorpyrifos 15G per acre and making more than one application per season. Rutabaga tops must not be used for food or feed.

PEST INFESTATION AND DAMAGE

Major insect pests of rutabaga are the cabbage webworm, *Hellula rogatalis* (Hulst); the harlequin bug, *Murgantia histrionica* (Hahn); the variegated cutworm, *Peridroma saucia* (Hubner); the yellowstriped armyworm, *Spodoptera ornithogalli* (Guenee); and the cabbage maggot, *Delia radicum* (Linnaeus) (Sorensen and Baker, 1983).

Libby, et al., (1974) observed that cabbage maggot causes considerable damage to rutabaga in Wisconsin. Larvae tunnel in stems and fleshy roots. Tunnels where maggots have fed become brown and slimy. Fungal organisms are likely to be introduced at these points. The long growing period allows two to three generations of cabbage maggot each year. Damage is accentuated by the oviposition preference of the maggot for rutabaga over other Cruciferae. Rutabaga must be protected from June to October, the interval from planting to harvest. In Canada, Tolman, et al. (1986) found a yield loss of 88 percent in rutabaga from the cabbage maggot and weeds, combined.

PEST MANAGEMENT

Current Chemical Usage

The results of the National Agricultural Pesticide Impact Assessment Program (NAPIAP) pesticide use assessment survey indicate that all rutabaga acreage in Oregon receives one application of chlorpyrifos at planting. Chlorpyrifos 4E is used on 30 percent of the crop, and chlorpyrifos 15G is used on 70 percent. Michigan and Washington also reported that all rutabaga acreage is treated with chlorpyrifos. No other insecticides are registered on rutabaga for the cabbage maggot.

Comparative Performance

Chlorpyrifos is the only insecticide registered on rutabaga for the cabbage maggot. The efficacy of experimental compounds is discussed in the "Future Pest Management Options" section of this chapter.

Nonchemical Alternatives

Bracken (1990) studied the use of entomogenous nematodes for control of the cabbage maggot in the laboratory. It was concluded that control on rutabaga would require strains or species considerably more lethal than those currently under study.

Pesticide Resistance

Dufault and Sears (1982) suspect resistance of cabbage maggot larvae to organophosphorus and carbamate insecticides.

Impact on Beneficial Insects

Chlorpyrifos 4E is known to be toxic to bees; however, planting-time applications occur at a time of the year when there is minimal risk to bee populations.

Integrated Pest Management

Dapsis and Ferro (1983) attempted to model cabbage maggot development rate in an effort to better time insecticide applications. The model has not been tested under field conditions. Sears and Dufault (1986) were not successful in using sticky boards to monitor flight activity and predict damage to rutabaga.

FUTURE PEST MANAGEMENT OPTIONS

Mackenzie, et al. (1987) found that chlorpyrifos was as effective as chlorfenvinphos, and more effective than fensulfothion and diazinon for cabbage maggot control in root and stem crucifers.

Read (1976) compared performance of several other pesticides with that of chlorpyrifos. The percent of marketable roots ranged as follows: 0 (untreated); 84-95 (chlorpyrifos); 86-97 (propoxur); 86-100 (fensulfothion); 67-100 (fonofos); 29-100 (isofenphos); 73-93 (terbufos); 81-88 (carbofuran); 39-88 (fenamiphos); 76-84 (phorate); 7-53 (pirimiphos-ethyl) and 0 (leptophos).

Young et al. (1987) studied the effects of insect growth regulators (IGR's) on the cabbage maggot under laboratory conditions. The results of their study suggest that two IGR's possess promising control potential against the maggot. Work has not been done, however, on field applications.

Foster observed that experimental compounds under study over the past 10 years do not last long enough in the field for rutabaga (J.E. Foster, 1991, personal communication).

SUMMARY

Approximately 200 acres of rutabaga production were treated with chlorpyrifos 4E. If chlorpyrifos 4E were to be canceled, chlorpyrifos 15G, which is equally efficacious, would be the only labeled alternative. Chlorpyrifos 15G is applied to approximately 400 acres of rutabaga production. In the event of cancellation of the 15G formulation, chlorpyrifos 4E would be the only labeled alternative.

Cancellation of either the sprayable or the granular formulations of chlorpyrifos would require some farmers to make equipment modifications. If both formulations were canceled, no labeled alternatives would be available, and production losses of rutabaga would exceed 58 percent. This production loss could force many growers out of rutabaga production and into alternative crops.

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Pesticides used improperly can be injurious to human beings, animals, and plants. Follow the directions and heed all precautions on labels. Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides where there is danger of drift when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment, if specified on the label.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S. Environmental Protection Agency, consult your local forest pathologist, county agriculture agent or State Extension specialist to be sure the intended use is still registered. Use only pesticides that bear the EPA registration number and carry appropriate directions.